EFFECT OF LONG-TERM PHOSPHATE FERTILIZATION ON CATION EXCHANGE CAPACITY (CEC) AND CATION MOVEMENT IN VARIABLE-CHARGE SOILS

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ABSTRACT

Soil profile samples collected in 10 and 15 cm increments to a depth of 60 cm from residual phosphate experiments on two soil families were used to investigate the effect of long-term P fertilization on CEC and cation movement in variable-charge soils. Increases in NH_4OAc - CEC and ECEC of 0.37 and 0.16 me/100 g per 100 ppm of applied P, respectively, were observed in the 0-10 cm layer in the Hydric Dystrandept from Hawaii. In the Tropeptic Eutrustox at the Waialua and Waipio sites, however, where relatively low rates of phosphate were applied, increases in CEC were not statistically significant at the 10% level. Leaching of cationic nutrients was decreased as a result of increased CEC in the Hydric Dystrandept. The level of divalent cations extracted was in the order NH_4Cl > NH_4OAc > EUF. For K and Na the order was NH_4OAc > NH_4Cl > EUF. A single extraction with 1 N NH_4OAc removed from 70% to 95% of the total amount of extracted divalent cations, suggesting that conventional extraction with 1 N NH_4OAc does not give complete removal of divalent cations in these variable-charge soils. The results further indicated that the first P increment was the most effective in increasing maize grain yield. The concentration of N, P, K, and Mg in maize

grain increased with increasing rates of applied phosphorus. P application, however, had no effect on the concentration of Ca in maize grain.

A balance sheet approach indicated that the amount of cationic nutrients unaccounted for decreased in the order K > Mg > Ca.

Correlation studies suggest that the initial levels of K in the soil determined by the NH_4OAc and the EUF_{III} - K represent the form of K taken up by maize, whereas Ca and Mg extracted by NH_4OAc and NH_4Cl were more closely correlated with Ca and Mg uptake than EUF extracted Ca and Mg. EUF - P was more closely related to P uptake than P found by the modified Truog method.

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I. INTRODUCTION

In modern farming lime and fertilizer costs constitute a substantial portion of the total production costs. Because of the growing world energy crisis the cost of lime and fertilizers can be expected to increase in the foreseeable future. There is a great deal of interest, therefore, in exploring ways for increasing fertilizer use efficiency. According to Parr (1973) this can be achieved by (i) minimizing losses of nutrients from the soil-root zone, and (ii) manipulating environmental and management factors in order to allow the plant to fulfill its genetic capability. This in itself would enhance the recovery of applied nutrients.

Losses of bases (Ca, Mg, K, etc.) can be minimized by increasing the negative charge, and therefore the cation exchange capacity of soil colloids since CEC is related to surface charge density σ through a specific surface term S (Gillman, 1980) as

$$CEC = \sigma S$$

Increases in CEC of variable-charge soils as a result of P application have been demonstrated under laboratory conditions (Mattson and Hester, 1935; Prince and Toth, 1936; Toth and Bear, 1947; Coleman and Mehlich, 1948; Mekaru and Uehara, 1972; Sawhney, 1974; Ryden and Syers, 1975). The question

arises, however, as to whether field applications of phosphate contribute materially to the improvement of soil fertility by regenerating or building up the cation holding complex of soil colloids. There is a need to further investigate this phase of the problem of phosphate fixation in order to determine the movement of cationic plant nutrients as a function of increasing P applications. Moreover, the establishment of a balance sheet for exchangeable cations can be of great importance in the determination of the fate of bases applied in fertilizers. Since the farmer needs to know the amount of effectively available nutrients in his soil in order to adjust his fertilizer rates, a more detailed evaluation of the status of nutrients in the soil by more precise methods is needed.

The objectives of this study were to

a) Investigate the effects of long-term phosphate fertilization on the cation exchange capacity of variable-charge soils and on the movement of cations in the soil profile.

b) Compare methods for determining exchangeable cations in soils (1 N NH_4OAc, 1 N NH_4Cl, Electroultrafiltration) for accuracy and relative sensitivity to variations in exchangeable cations due to soil depth and P applications.

II. LITERATURE REVIEW

A. Phosphate-Induced Cation Exchange Capacity

According to Pratt (1978) a quantity of any cation that goes into the soil root zone can be removed in harvested crops, leached, or accumulated in the root zone. He expressed this relationship as:

$$M_i - M_c - M_p - M_a = 0$$

where M is any given cation and i, c, p, and a refer to the input, crop removal, leached, and accumulated cations, respectively. There is sufficient evidence to suggest that a certain amount of control can be exerted on the leaching of cations beyond the rooting zone. The amount of bases in the soil exchange complex can be increased or decreased, depending on the nature of the fertilizers applied to the soil. Moreover, the introduction of different fertilizers into the soil over a period of years is expected to exert a measurable effect on the exchange complex. This might be the case when phosphate fertilizers are applied to highly weathered soils of the humid tropics which are characterized by surfaces having a constant surface potential (van Raij and Peech, 1972). In effect, the increase in negative charge resulting from the sorption of inorganic phosphate by soil colloids has been established under laboratory conditions in several studies. Prince and Toth (1936), Toth (1937),

Davis (1945), Coleman and Mehlich (1948), and Perkins (1958) reported an increase in the cation exchange capacity due to phosphate anions. Mekaru and Uehara (1972) reported an increase in CEC of about 0.8 me/m mole of phosphate adsorbed by ferruginous tropical soils. A similar increase in CEC was reported by Galindo and Bingham (1977) whose results showed that as the adsorbed phosphate increased, the positive charges decreased to zero while the negative charges increased an average of 0.8 me/m mole of P adsorbed. Further, they stated that their results were in general agreement with the predictions of the theory of Hingston and coworkers (1967, 1968, 1972). According to this theory adsorption of an anion of a weak acid not only neutralizes the positive charges, but can be adsorbed at pH values higher than the ZPC of the substrate providing the pH is somewhere near a pKa of the acid.

In a study with six Connecticut Inceptisols (Sawhney, 1974) the increase in CEC varied from 11 to 88% with phosphate sorption from dilute solutions. The amount of P required to produce an increase of 1 me in CEC varied with pH, i.e., 80 mg P at pH 5 and 40 mg P at pH 7.5. As Sanchez (1980) pointed out, increases in cation exchange capacity due to P applications reported in the literature range from 0.08 to 0.9 me/100 g per 100 ppm P added. This variability can be attributed, at least in part, to the mineralogical composition of the soils involved as well as the methods of measuring electric charges. It has been shown that the

magnitude of the increase in CEC is greater in oxidic than kaolinitic soils (Coleman and Mehlich, 1948). Moreover, according to Stoop (1974) the magnitude of the increase will be dependent on the extent of sorption vs precipitation mechanisms. Stoop (1974) has pointed out that if all the P added is precipitated, the increase in CEC is likely to be negligible. On the other hand Sawhney (1974) and Schalscha et al. (1974) have suggested that not all the P sorbed contributes to the increase in negative charge. Recently Ryden and Syers (1975) have demonstrated that P sorption can occur, at final P concentrations from 1.5 to 25 m mole liter^{-1} and between pH values of 4 and 7, without an increase in negative charge.

B. Mechanisms of P-Induced CEC

As pointed out earlier, methods of measuring electric charges can have a crucial bearing on subsequent interpretations concerning the mechanism of pH-dependent CEC and the actual status of charges under field conditions (Fey and Le Roux, 1976). In fact, different causes of phosphate-induced cation exchange capacity are found in the literature: (i) a shift in the zero point of charge (ZPC) to lower pH's (Hingston et al., 1967, 1972, 1974; Breeuwsma and Lyklema, 1973; Jepson et al., 1976; Parfitt and Atkinson, 1976; Wann and Uehara, 1978), (ii) neutralization of positive charge (Hingston et al., 1972, Schalscha et al., 1972) and (iii) electrolyte imbibition (Thomas, 1960).

The apparent disagreement about the causes of phosphate-induced CEC is evidence that the mechanisms involved in phosphate sorption-desorption reactions remain largely obscure. Recently, however, an attempt has been made by Ryden and Syers (1975) to quantitatively evaluate the different mechanisms of P sorption generally found in the literature. They found that phosphate sorption data, after transformation according to the Langmuir equation, were described by three distinct linear relationships denoted as regions I, II, and III. Ryden and Syers (1975) suggested that the reaction mechanisms represented in equations (1), (2), and (3) below were responsible for sorption of phosphate in regions I, II, and III, respectively.

$$M - OH_2^+ + H_2PO_4^- = M - H_2PO_4 + H_2O \quad (1)$$

$$M - OH + H_2PO_4^- = M - H_2PO_4 + OH^- \quad (2)$$

$$M - OH + HPO_4^{2-} = M - HPO_4^- + OH^- \quad (3)$$

where M = Fe or Al.

It follows that phosphate sorption in regions I and III involves an increase in the negative charge of the surface, whereas no change in surface charge occurs during sorption in region II.

Most of the investigations on the effects of phosphate fertilizers on the cation exchange capacity of variable-charge soils reported in the literature were carried out under laboratory conditions with a relatively short period of reaction of inorganic phosphate with the

soil. However, recently Gillman and Fox (1980) using soils from field plots which were fertilized with concentrated superphosphate for eight years found significant increases in CEC of the surface horizons of three variable-charge soils of Hawaii. This suggests that increases in CEC produced by P treatment of variable-charge soils are permanent. Gillman and Fox (1980) reported that the leaching of applied nutrients (Ca, Mg, K) was consequently retarded. They explained the fact that the first increment of P increased CEC more than later increments by the mechanism of P sorption on hydrous oxides proposed by Rajan (1976).

It follows from Figure 1 that when an aquo group is replaced the positive charge is decreased, and as a result the net negative charge is increased. On the other hand, the replacement of a hydroxyl group leaves the surface charge unaltered. It will be seen from Figure 1 that the reaction mechanism leading to a decrease in positive charge and, therefore, an increase in net negative charge is the same as the sorption of phosphate in region I suggested by Ryden and Syers (1975). As Rajan (1976) pointed out at low surface saturation most of the aquo groups are displaced by phosphate owing to their greater lability. However, the proportion of hydroxo groups released increases as the saturation increases, showing that phosphate is adsorbed mostly by displacing hydroxyl ions. It should be pointed out that Ryden and Syers (1975) studied P sorption at approximately the natural pH of the soil, covering the range of 4.6 to 8.1,

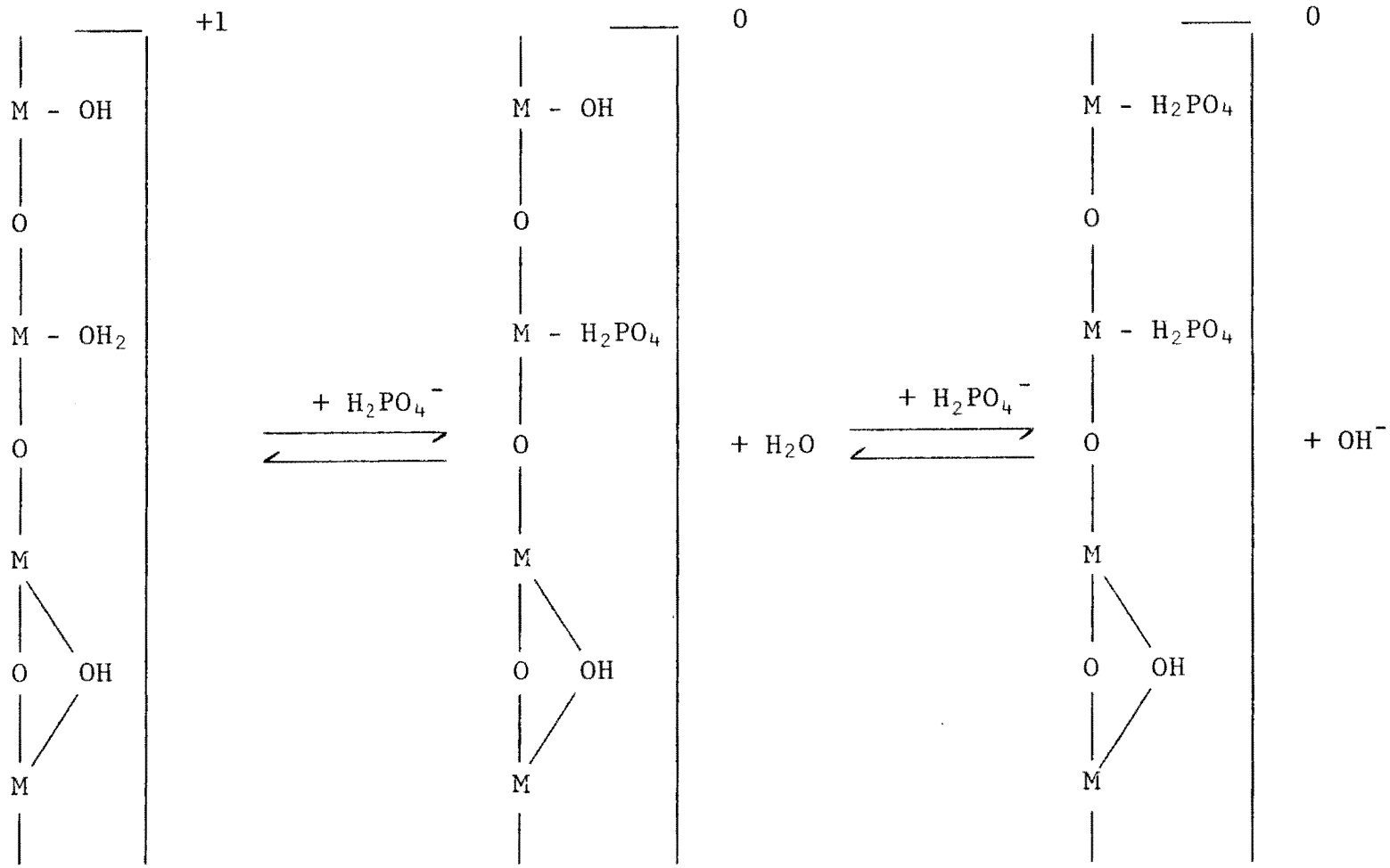


Fig. 1. Probable mechanism of phosphate adsorption

whereas Rajan (1976) conducted P sorption experiments at a constant pH of 5.0. The soils investigated by Gillman and Fox (1980) had a natural pH ranging from 4.7 to 5.0.

It should be pointed out that the results obtained by Gillman and Fox (1980) showed that the increase in CEC as a result of phosphate fertilization was obscured by the fact that these soils were limed to about pH 6. The effect of lime on cation exchange properties of soils is well known. According to Uehara and Keng (1975) when lime is added and mixed with the top soil most of the lime is consumed to create negative charge by increasing pH. In effect, Smyth and Sanchez (1980) reported an increase in net negative charge from 11 to 47% with application of lime and silicate to an Oxisol, the amendment effects being not significantly different among sources. However, the combination of amendment and P treatment increased the negative charge and decreased the positive charge to a greater extent than when these treatments were applied separately.

C. Methods of CEC Determination

Earlier it was pointed out that the methods of measuring electric charges can have a crucial bearing upon the interpretation of the actual status of charges under field conditions. This is specially true when charges are estimated by routine measurement of cation exchange or anion exchange capacities. An estimate of cation exchange capacity (CEC) results from treating a soil sample with a salt

solution, removing the free salt by washing and determining the amount of retained index cation that is replaceable by another cation. Many workers have compared groups of methods in order to find those most suited to their needs or those which they believe to be the most reliable. As pointed out by Tucker (1960), however, the criteria used by these workers may vary. He indicated that some workers choose the method which gives the largest value of the properties being measured (Mandal, 1952; Golden et al., 1942), whereas others aimed at methods which give close agreement between cation exchange capacity and the sum of exchangeable cations (Pratt and Holowaychuck, 1954). It should be pointed out that some methods have been rejected because they do not completely replace exchangeable cations (Barrows and Drosdoff, 1958; de Leenheer and Maes, 1954). However, according to Tucker (1960) this can be considered as an arbitrary test since there is no upper limit to the reaction of soil exchanges with alkalis except destruction of the exchange complex.

Neutral 1 N NH_4OAc displacement is a commonly-used method for CEC determination. However, as Tucker (1960) pointed out the acetate anion is not suitable as it tends to extract organic compounds from soils and enhance the solubility of non-exchangeable cations above that in the presence of strong acid anions. On the other hand, the use of a solution of high ionic strength seems unjustified for soils dominated by variable charge colloids since these soils are

bathed by solutions of ionic strength rarely exceeding 0.005 (Bell and Gillman, 1978). The use of a saturating solution of pH 7 in variable-charge soils is also questionable. Finally, as pointed out by Sumner (1963) methods involving alcohol washing do not give a true reflection of the charge present in the soil since alcohol washing may cause a shift in the pH of the system to the acid side, causing a decrease in negative charge as a result of proton transfer.

NH_4Cl method is also widely used in CEC determination. Unlike the acetate anion, however, the chloride anion is not specifically adsorbed by soil colloids and therefore cannot generate additional electric charges. An alternative procedure which, according to Juo et al. (1976) is probably the most realistic, involves the summation of 1 N NH_4OAc exchangeable bases plus the 1 N KCl exchangeable acidity. The CEC determined in such a manner is called the "effective CEC."

However, as Bell and Gillman (1978) pointed out, although the disadvantages of conventional methods for measuring charge characteristics of soils dominated by variable charge colloids are now widely recognized, no universally accepted method has been devised for these soils.

D. Methods for Determining Exchangeable Cations

As for cation exchange capacity many methods have been developed for determining exchangeable cations in soils. These are relatively fast and inexpensive. One of the

consequences of this diversity of methods, however, is that comparison of measurements made in different laboratories is often difficult and in some cases impossible.

Ammonium acetate (NH_4OAc) is widely used as a replacing salt. However, as Tucker (1960) pointed out, the acetate anion is not suitable because it tends to extract organic compounds from soils and to enhance the solubility of non-exchangeable cations. He therefore recommended ammonium chloride (NH_4Cl) instead. The possibility of fixation of the ammonium ion by some minerals still remains, but according to Tucker (1960) it is probably small under the conditions of the equilibration. According to Ne'meth (1979) the correlation between the values obtained by chemical methods and nutrient uptake as well as fertilizer requirements are unsatisfactory. Only methods capable of determining both the nutrient concentration of the soil solution and the buffering of the nutrient concentration in the course of the growing period are suitable to provide significant correlations with nutrient uptake (Ne'meth, 1979). One of these methods is electroultrafiltration (EUF). EUF combines techniques of electrodialysis and ultrafiltration. It is a water extraction process, accelerated by an electric field of varied voltage. In the electric field the cations (Na^+, K^+, NH_4^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Al^{3+}, etc.) are attracted by the cathode and the anions (PO_4^{-3}, SO_4^{-2}, NO_3^-, negatively charged clay, etc.) by the anode. One of the main advantages of EUF over conventional soil testing methods is that several important

plant nutrients are determined in a single extract. Furthermore, it allows differentiation between immediate and potential availability of nutrients.

III. MATERIALS AND METHODS

A. Field Study and Soil Description

This investigation was carried out on the experimental plots of the University of Hawaii Benchmark Soils Project and the Waialua Sugar Company, Inc. Experiments of the Benchmark Soils Project are carried out on selected soil families (as defined in Soil Taxonomy) which are found in several countries to test the hypothesis that agrotechnology developed in a particular soil family in one location can be transferred to the same soil family in another location. Residual phosphate experiments on two soil families in Hawaii were sampled before planting maize as the test crop. At Kukaiau, the soil was a Kukaiau silty clay loam of the thixotropic, isothermic Hydric Dystrandept family and at Waipio, it was a Wahiawa silty clay of the clayey, kaolinitic, isohyperthermic, Tropeptic Eutrustox family. Profile descriptions of these two soils are shown in Appendix A.

A third site sampled was an amount of phosphorus fertilizer experiment being conducted by the Hawaiian Sugar Planters' Association (HSPA) with sugarcane at Waialua Sugar Company. The soil is also a Wahiawa silty clay of the clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox. Finally, a fourth site in the Philippines which is part of the Benchmark Soils Project network was also

sampled in order to determine the effect of past history on soil characteristics. Soil at this site is also a silty clay loam of the thixotropic, isohyperthermic Hydric Dystrandept family and appeared to be a former home site with an associated accumulation of organic residues. Maize growth at this site was exceptionally vigorous without fertilization while a few meters away maize growth was very poor without fertilization. Samples were collected from both the fertile and infertile areas of this site.

Soil profile samples were collected from the field experiments. On each plot four soil cores were taken in 10 or 15 cm increments to a depth of 60 or 105 cm. The samples from a given depth in a treatment were composited. The samples of the Hydric Dystrandept were stored in sealed plastic bags to prevent drying until the chemical analyses were completed, whereas the Wahiawa soil samples were air-dried. Soil samples were passed through a 2-mm sieve before analysis. The experimental plots of the Hydric Dystrandept and Tropeptic Eutrustox sites of the Benchmark Soils Project were fertilized with low, medium, and high rates of phosphate for varying periods of time.

The P fertilizer was broadcast as treble superphosphate in 1975 and 1977 on the Hydric Dystrandept and in 1977 on the Tropeptic Eutrustox sites of the Benchmark Soils Project. P fertilizer was then mixed with the top 15 cm of the soil. Four weeks before planting corn, *Zea mays L.*

Table 1

Coded Values and Rates of P Treatments
in Experiments by Soil Family

Soil Family	Treatment	Phosphorus	
		Coded Level	Actual Level KgP/ha
Hydric Dystrandept	P	Partial Control	0
	K	-0.85	40
	J	0	396
	L	+0.85	750
Tropeptic Eutrustox	P	Partial Control	0
	K	-0.85	10
	J	0	65
	L	+0.85	140

(Cultivar X 304C from the Pioneer Seed Co.), lime was applied on the Hydric Dystrandept at a rate of 180 kg Ca/ha. The material was broadcast by hand on plots that measured 3 x 6 meters and roto-tilled. Soil samples were collected before lime application. Prior to the planting of corn nitrogen, potassium, magnesium, zinc and boron were applied on the Hydric Dystrandept at rates of 115, 200, 100, 15, 5 kg/ha and on the Tropeptic Eutrustox at rates of 108, 100, 100, 15 and 2 kg/ha, respectively. An additional 56 kg N/ha and 72 kg/ha as urea was applied during the growth of the plants on the Hydric Dystrandept and Tropeptic Eutrustox, respectively. Maize was planted on the Hydric Dystrandept and the Tropeptic Eutrustox in July and August 1981, and harvested in November and December 1981, respectively.

At harvest, whole-plant samples were collected from the maize plots. Corn ears were separated from stalks and leaves, dried at 60°C and ground in a stainless steel Wiley mill. After harvest, soil samples were again taken from the maize plots of the Hydric Dystrandept and the Tropeptic Eutrustox.

In the HSPA experiment, P fertilizer was banded at a depth of 10-12 cm. The rates of P applied were 0, 98, and 196 kg/ha. Sugarcane was grown in the plots. Soil samples (4 cores/plot) were collected when the cane was 8 months old. Soil cores were taken from the cane lines after removal of of the seedpiece at the following depths: 0-15, 15-30, 30-45, 45-60 cm.

B. Laboratory Determinations

1. Cation Exchange Capacity (CEC). Two methods for determining CEC were compared for accuracy and relative sensitivity to variations in CEC due to P applications.

a. Ammonium acetate method. To a 25 g sample of air-dried soil 50 mℓ 1 N NH_4OAc, pH 7.0 were added in a 250-mℓ Erlenmeyer flask. The flask was shaken for one hour, and then allowed to stand overnight. Using vacuum suction, filtration was carried out with a Buchner funnel using Whatman N^{o} 42 filter paper. The soil was washed with four 50-mℓ increments of 1 N NH_4OAc to completely saturate the soil cation exchange sites with ammonium ions. The filtrate and washings were secured for the determination of exchangeable cations. The soil retained on the filter paper was then washed with 100 mℓ of 95% methyl alcohol to remove excess NH_4OAc. NH_4^+ was extracted by washing with 240 mℓ of 10% acidified NaCl. The leachate was transferred to a 250-mℓ volumetric flask and the solution made to volume with NaCl. A 100-mℓ aliquot of the leachate was transferred to an 800-mℓ Kjeldahl flask, 50 mℓ of 1 N NaOh and a few pieces of mossy zinc and glass beads were added. The NH_4^+ in the NaCl extract was distilled into 50 mℓ 2% boric acid with 10 drops of mixed indicator (methyl red plus brom cresol green) until two thirds of the extract was distilled. Standard sulfuric acid was used to titrate the distillate.

B. Ammonium chloride method (1 N NH_4Cl). The procedure was the same as that described for NH_4OAc - CEC. The pH of the NH_4Cl was initially adjusted to pH 7.

2. Exchangeable cations.

a. Extractable bases (Ca, Mg, K, Na) were determined in the NH_4OAc and NH_4Cl extracts using the Perkin Elmer model DCR 1 303-0177 atomic absorption spectrophotometer. To prevent interferences by other ions 1 mℓ 0.2% lanthanum oxide was added to each extract as well as the standard solution.

b. Exchangeable cations were also determined by electroultrafiltration (EUF) on selected soil samples. EUF is a combination of electrodialysis and ultrafiltration which has been developed in the Federal Republic of Germany as a technique of soil analysis (Ne'meth, 1972). EUF is a water-extraction process controlled by variation in voltage, temperature, and time. The principle of the method is as follows: When an electrical potential is applied to a soil suspension se-eral reactions can occur. For example, at the cathode these reactions can occur:

$$2Na + 2e^- \longrightarrow 2Na^0 \text{ (metal reduction)}$$

$$2Na^0 + 2H_2O \longrightarrow 2NaOH + H_2 + 67.4 \text{ Kcal}$$

Similar reactions can take place with K, Mg, Ca, etc.

At the anode, oxidative processes take place. For example:

$$NO_3^- - e^- = [NO_3]$$

$$[NO_3]\cdot + H_2O \longrightarrow NO_3^- + H^+ + [OH]$$

$$2[OH]\cdot = H_2O_2 \longrightarrow H_2O + \tfrac{1}{2}O_2$$

The rate at which ions are extracted depends on the rate of desorption from the clay particles and the rate of transport of ions to the electrodes. The former is directly proportional to the voltage applied and inversely proportional to the binding energy of the ions. The latter is directly proportional to the field intensity. As pointed out by Ne'meth (1972), at a given voltage the quantity of ions extracted in a given time is governed by the friction coefficient of the ion which in turn is determined by its concentration. At a given voltage, the transport of ions is more rapid, the higher their concentration. The rate of ion migration in electroultrafiltration is therefore not constant at a given voltage and temperature, but decreases during the extraction. On the other hand, the speed of ion migration in the electrical field is raised with an increase in temperature.

A schematic diagram of the EUF apparatus is presented in Figure 33 in Appendix E. A three-cell apparatus is used in electroultrafiltration. The middle cell containing the soil suspension (soil:water = 1:10) has a stirrer and a water inflow. Each side of this central cell is provided with a micropore filter attached to the platinum electrodes that separate the middle cell from the two outside compartments. These two other cells have vacuum connections. Therefore, the hydroxides (NaOH, KOH, Ca(OH), NH_4OH, etc.) accumulating at the cathode and the acids (HNO_3, H_2SO_4, etc.) accumulating at the anode are washed away by the continuous stream of

water to the collecting tanks. The pH of the soil suspension remains constant during EUF extraction in contrast to the situation that prevails with electrodialysis. The fractions are gathered in separate channels and led to a fraction collector.

The negatively-charged clay minerals of the soil migrate to the anode and are deposited on the anode filter. The water permeability of the anode filter is reduced by the accumulation of clay. The amount of water flowing through this filter is therefore inversely proportional to the clay content, so that the latter can be determined indirectly.

According to Ne'meth (1979) the quantity of effectively available nutrients is reproduced very well at low voltages (50 and 200 V) and at 20°C for 30 minutes. On the other hand, the rates of desorption at 400 V and 80°C characterize the nutrient reserve.

Twenty soil samples were sent to the Justus Liebig University, Giessen, West Germany, for EUF determination of P, Ca, Mg, K, and Na. The determination was carried out as follows:

A 5 g sample of air-dried soil was used for each extraction. The samples were extracted by EUF with stepwise increase in voltage and temperature. Seven EUF aliquots were collected at 5-minute intervals. The voltage and the temperature were altered during the extraction time and were 50 V and 20°C for the first 5 minutes, then 200 V and 20°C from 5 to 30 minutes and 200 V and 80°C from 30 to 35 minutes.

3. Soil pH. Soil pH was determined in water and in 1 N KCl with a soil-to-solution ratio of 1:1 after 30 minutes of equilibration using a Beckman pH-meter.

4. Exchange acidity and exchangeable aluminum. To a 5 g sample of air-dried soil 125 mℓ 1 N KCl were added in a 250-mℓ Erlenmeyer flask. The flask was then shaken by hand several times, allowed to stand for 30 minutes, and then the suspension was filtered through Whatman No. 42 filter paper. A 1.0-mℓ aliquot of the filtrate was transferred to a 250-mℓ beaker, and 5 drops of phenolphthalein indicator were added. The exchange acidity was determined by titration of the solution with standard NaOH to a permanent pink point. Then 1 mℓ of 0.1 N HCl was added to make the solution colorless and 1 mℓ 1 N NaF were added. The color became pink again if Al was present in solution. Exchangeable Al was determined by titrating the solution with standard HCl until the pink color disappeared.

5. Extractable P. Extractable phosphorus was determined by a modified Truog method. A 2.0 g soil sample was shaken with 200 mℓ of 0.02 N H_2SO_4 solution containing 3.0 g ammonium sulfate per liter for 30 minutes in a 500-mℓ Erlenmeyer flask. The suspension was filtered through Whatman No. 42 filter paper, and P in the extract was determined colorimetrically by the method of Murphy and Riley (1962).

6. Effective CEC (ECEC). The CEC determined by this method is the sum of NH_4OAc - extractable bases and the 1 N KCl - exchangeable acidity.

C. Analysis of Data

Standard statistical methods of analysis of variance, regression and correlation were used for the analysis of data. Significant differences between treatment means were determined using Duncan's multiple range test.

IV. RESULTS AND DISCUSSION

A. Effect of Phosphate Application on Extractable Soil P

1. Hydric Dystrandept. Data for the P extracted by the modified Truog method from soil samples taken before planting are presented in Tables 2 and 3 for the Kukaiau soil and the soil from the Philippines, respectively. For the Kukaiau soil the values of extractable P are unreasonably high. The modified Truog method, which uses an acid extractant, does not seem suitable for the estimation of extractable soil P under the specific conditions of this soil perhaps because of previous massive applications of rock phosphate in this soil. In spite of this, there is a significant increase in extractable P in the top 20 cm with increasing rates of P applied. For the soil from the Philippines the increase in extractable P occurred not only in the top 20 cm, but also in the underlying layers. It should be noted that P levels in the high P area were significantly higher than those in the low P area to the 30-45 cm depth. At the 45-60 cm depth, however, the reverse was true. The high P levels may have resulted to some extent from the deposition of organic residues and other debris since the high P area was previously a house site. In both soils the level of extractable P decreased with depth. A possible explanation is that the phosphate retention capacity of the Hydric Dystrandept is so great that there is

Table 2

Effect of P Fertilization on Modified Truog Extractable Soil P* of a Hydric Dystrandept from Hawaii Kukaiau Site

Depth (cm)	P Applied, kg/ha			
	0	40	396	750
	ppm			
0-10	72.2** cd	115.7 b	173.2 a	189.3 a
10-20	62.1 d	76.8 cd	94.9 bcd	109.1 bc
20-30	65.0 d	73.0 cd	75.1 cd	69.3 d
30-45	79.5 cd	68.8 d	72.0 cd	79.4 cd
45-60	73.5 cd	76.2 cd	72.8 cd	76.6 cd

* Average of 3 replicates

** Averages followed by the same letter are not significantly different from each other at the 5% level.

Table 3

Modified Truog Extractable Soil P* of a Hydric Dystrandept from the Philippines

Depth (cm)	Low P Area	High P Area
	ppm	
0-10	28.04** b	34.35 a
10-20	22.63 c	30.51 b
20-30	10.51 e	17.82 d
30-45	11.50 e	15.40 d
45-60	16.90 d	11.74 e

* Average of 2 replicates for analytical determination

** Averages followed by the same letter are not significantly different from each other at the 5% level.

little, if any, P movement. Table 46 in Appendix F shows the levels of extractable soil P as determined by the modified Truog and EUF methods. The quantitites of P obtained in the first six aliquots (0-30 minutes at 200 V and 20°C) in the EUF method were summed and considered to represent the readily available P.

EUF - P values were consistently much lower than the levels of P found by the modified Truog method. One possible explanation of the unreasonably low EUF - P values is that during the extraction process the negatively-charged soil particles accumulating at the anode reduce the quantity of P transferred into the anode extracts due to physical obstruction by the clay as well as sorption of P by the clay particles. As a result, the quantity of P extracted in the EUF middle cell will decrease with decreasing volumes of the anode extracts (Ne'meth, 1972). In the 0-10 cm layer EUF - P values increased slightly with P application; however, the observed increase was not significant at the 5% level. The coefficient of variation (CV) for the EUF - P levels was 35%, whereas the CV for modified Truog P was 22%

2. Tropeptic Eutrustox. The trends recorded for the Hydric Dystrandept were also observed for the Tropeptic Eutrustox (Tables 4 and 5), viz., the level of extractable P increased with increasing rates of P applied. However, unreasonably high values of extractable P were obtained for the 0-15 cm depth in the Waialua soil, presumably because of uncertainties regarding the actual point of sampling relative

Table 4

Effect of P Fertilization on Modified Truog Extractable Soil P* of a Tropeptic Eutrustox-Waipio Site

Depth (cm)	P Applied, kg/ha			
	0	10	65	140
	ppm			
0-10	24.46** bcd	28.64 b	38.02 a	45.26 a
10-20	21.18 bcdef	23.69 bcde	27.38 bc	27.81 bc
20-30	15.27 efgh	19.97 cdefg	18.01 defgh	14.37 fghk
30-45	11.38 ghklm	12.02 ghkl	11.88 ghkl	9.63 hklm
45-60	3.08 m	5.05 lm	6.15 klm	4.65 lm

* Average of 3 replicates

** Averages followed by the same letter are not significantly different from each other at the 5% level.

Table 5

Effect of P Fertilization on Modified Truog Extractable Soil P* of a Tropeptic Eutrustox-Waialua Site

Depth (cm)	P Applied, kg/ha		
	0	98	196
	ppm		
0-15	17.71** cd	100.51 b	215.30 a
15-30	16.13 cd	22.87 c	19.91 cd
30-45	7.47 cd	8.89 cd	8.64 cd
45-60	6.19 d	7.59 cd	5.99 d

* Average of 4 replicates

** Averages followed by the same letter are not significantly different from each other at the 5% level.

to the phosphate fertilizer which was banded in this experiment. Again, in both soils, the level of extractable P gradually decreased with depth. Depending on the crop to be grown, it may not be advisable to ignore the low levels of extractable P in the subsoils. Table 47 in Appendix F shows the levels of extractable P as determined by the modified Truog and EUF methods. The trend recorded for the Hydric Dystrandept was observed for the Tropeptic Eutrustox, viz., the values of EUF - P were much lower than the levels of P extracted by the modified Truog method. On the other hand, EUF - P values in the 0-10 cm sample increased with P application. However, the observed increase was not significant at the 5% level. The coefficient of variation (CV) for the EUF - P levels was 33%, whereas the CV for modified Truog P was 25%.

B. Effect of P Fertilization on CEC

1. Hydric Dystrandepts.

a. 1 N $NH_4OAc_{(pH\ 7.0)}$ - CEC. The effect of phosphate application on the CEC of the Hydric Dystrandept from the Kukaiau site is depicted in Figure 2. Cation exchange capacity of soil material from the 0-10 depth increased significantly with increasing quantities of phosphate applied. The increase in CEC (ΔCEC) was about 4.13 me/100 g from the lowest to the highest rate of P applied, which is equivalent to an increase of 0.37 me/100 g per 100 ppm of P applied. The relationship between CEC and the cumulative rates of P

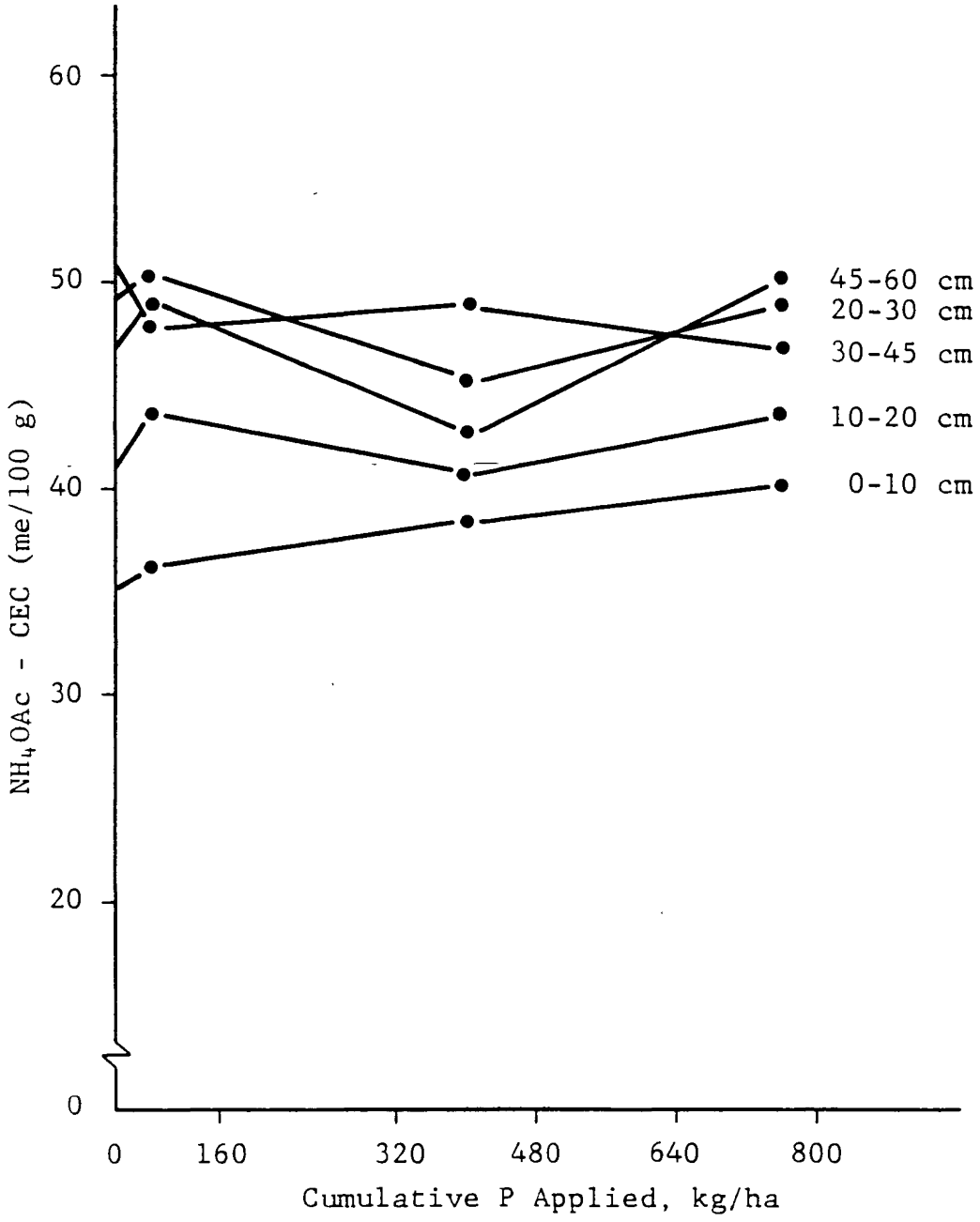


Fig. 2. Relationship between NH_4OAc - CEC and P applied for the Hydric Dystrandept at the Kukaiau site

applied was less pronounced in the 10 to 20 cm layer, perhaps because the lower portion of this layer was not directly phosphate fertilized. Beyond 20 cm P application had no effect on CEC.

For the soil from the Philippines (Table 6), increases in CEC as a result of high rates of P occurred even at a depth of 30-45 cm. However, since soil samples taken from the Philippines site were not replicated in the field, but in the laboratory, the variability in CEC in the field remains unknown. The significant differences shown are based on the variation between duplicate samples in the laboratory.

In both soils the CEC increased with depth perhaps because of the increase in specific surface since the cation exchange capacity of soil colloids is approximately equal to the product of the surface charge density σ and the specific surface area S (Gillman, 1980):

$$CEC = S\sigma$$

b. 1 N NH_4Cl - CEC. For the Hydric Dystrandept from the Kukaiau site (Figure 3), the increase in CEC from the lowest to the highest rate of P applied in the 0 to 10 cm layer was about 2.27 me/100 g, but was not statistically significant. Beyond 10 cm, phosphate application had no effect on CEC. For the soil from the Philippines (Table 7), a significant increase in CEC of about 5.0 me/100 g was recorded. As with NH_4OAc, NH_4Cl - CEC increased with depth. Large differences in CEC determined by the two methods were observed. The CEC values obtained by acetate displacement were

Table 6

Effect of P on NH_4OAc - CEC of a Hydric Dystrandept from the Philippines

Depth (cm)	Low P Area	High P Area
	me/100 g	
0-10	31.98 h	40.57 g
10-20	39.94 g	42.45 f
20-30	52.99 d	55.50 c
30-45	50.60 e	52.50 d
45-60	59.20 a	57.48 b

Averages followed by the same letter are not significantly different from each other at the 5% level.

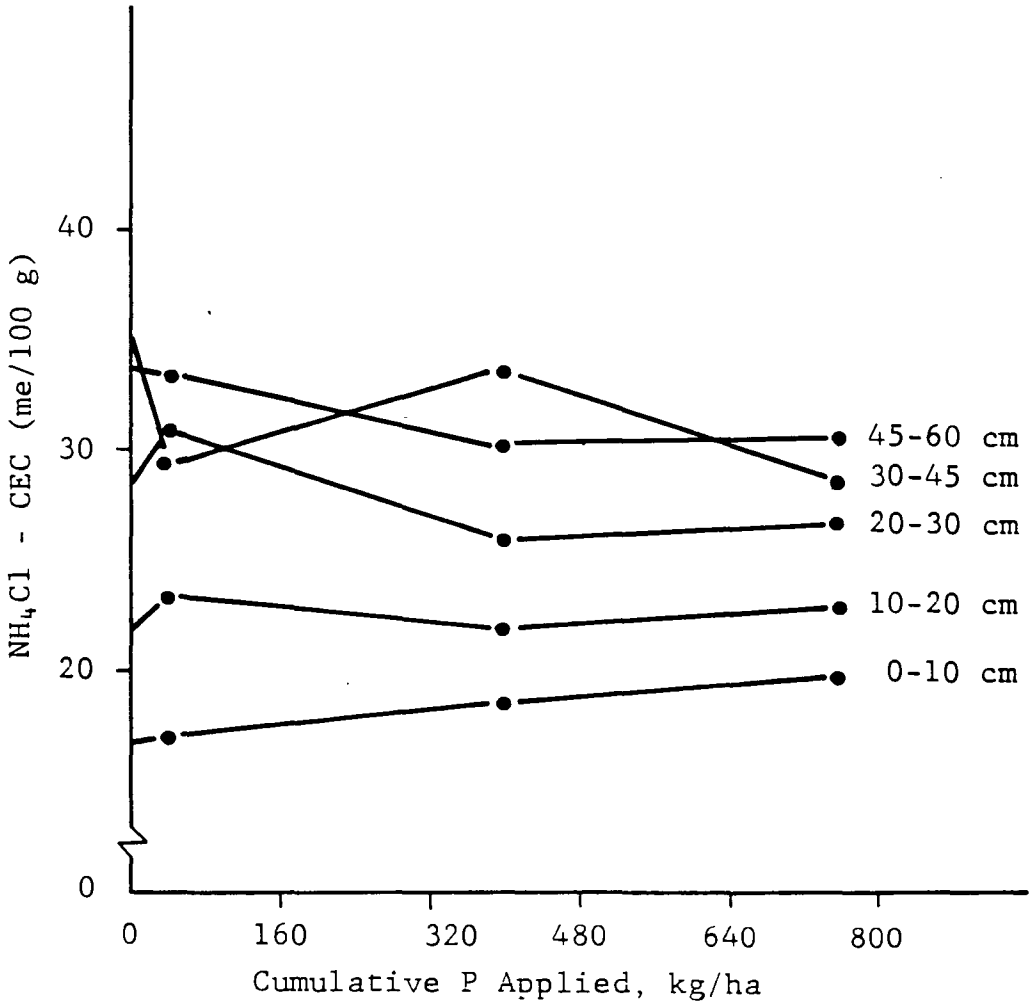


Fig. 3. Relationship between NH_4Cl - CEC and P applied for the Hydric Dystrandept at the Kukaiau site

Table 7

Effect of P on NH_4Cl - CEC of a Hydric Dystrandept from the Philippines

Depth (cm)	Low P Area	High P Area
	me/100 g	
0-10	17.84 e	22.86 d
10-20	23.56 d	24.70 d
20-30	30.79 c	31.07 c
30-45	28.60 c	29.78 c
45-60	44.65 a	40.34 b

Averages followed by the same letter are not significantly different from each other at the 5% level.

consistently higher than those determined by chloride displacement. The same pH (7.0) and the same saturating and displacing cations (NH_4^+ and Na^+, respectively) were employed for both measurements; however, NH_4Cl is not buffered as is NH_4OAc. Moreover, increases in NH_4OAc - CEC as a result of high P application were much higher than those in NH_4Cl - CEC. These results are in agreement with those reported by During (1973) with CaOAc and $CaCl_2$.

The differences in CEC narrowed with depth as is evident from the decrease in the ratio of NH_4OAc - CEC ÷ NH_4Cl - CEC (Table 8). It is likely that variation in the dominant minerals in different soil horizons is a major factor in the discrepancies in CEC determined by the two methods. However, other factors such as pH and anion effects may play a role as well. Some workers (El-Swaify and Sayeh, 1975) have suggested that the acetate anion can be specifically adsorbed by soils rich in oxides and hydrous oxides of Fe and Al with subsequent increase in negative charge. Moreover, according to Earl et al. (1979), NH_4OAc (pH 7) solution can precipitate exchangeable Al to form poorly crystalline hydrous $Al(OH)_3$ gels on colloid surfaces. These gels are sufficiently reactive to increase acetate anion retention. Such retention can be expected to decrease with depth because of the increase in soil pH. The contribution of organic matter to the increase in CEC is not known. It is, however, well established that heavy applications of phosphate can increase the organic matter content of soil because the

Table 8

Effect of P Treatments and Soil Depth on the Ratio of NH_4OAc - CEC ÷ NH_4Cl - CEC of a Hydric Dystrandept from Hawaii Kukaiau Site

Depth (cm)	P Applied, kg/ha			
	0	40	396	750
0-10	2.21	2.14	2.13	2.11
10-20	1.92	1.87	1.88	1.93
20-30	1.78	1.60	1.75	1.86
30-45	1.45	1.71	1.44	1.64
45-60	1.40	1.43	1.38	1.62

increased crop growth produces more roots which decompose to produce large amounts of organic matter. On the other hand, it should be pointed out that the experimental plots of the Kukaiau site were limed one month before the soil samples were taken. The possible interaction between lime and phosphate adds another uncertainty to the observed increase in CEC.

2. Tropeptic Eutrustox

a. 1 N NH_4OAc (pH 7.0) - CEC. The relationship between CEC and the rates of P applied is depicted in Figure 4 for the Tropeptic Eutrustox of the Waipio site. Phosphate rates had no significant effect (10% level) on CEC in the 0 to 10 cm layer. However, in the 10 to 20 cm layer the CEC in the highest P treatment was significantly higher (10% level) than that of the other P treatments. This, however, may have been due to random variation since the lower portion of this layer was not P fertilized and the phosphate retention capacity of the soil is sufficiently high so that movement by P can be expected to be nil. The possibility does exist, however, that P fertilizer may have been tilled into this depth.

For the Tropeptic Eutrustox of the Waialua site (Table 9), no significant effect of P on CEC was observed. However, the results of this experiment must be interpreted with caution since phosphate fertilizer was banded and although the seed piece was removed before sampling, the exact position of the P band may be uncertain and in addition,

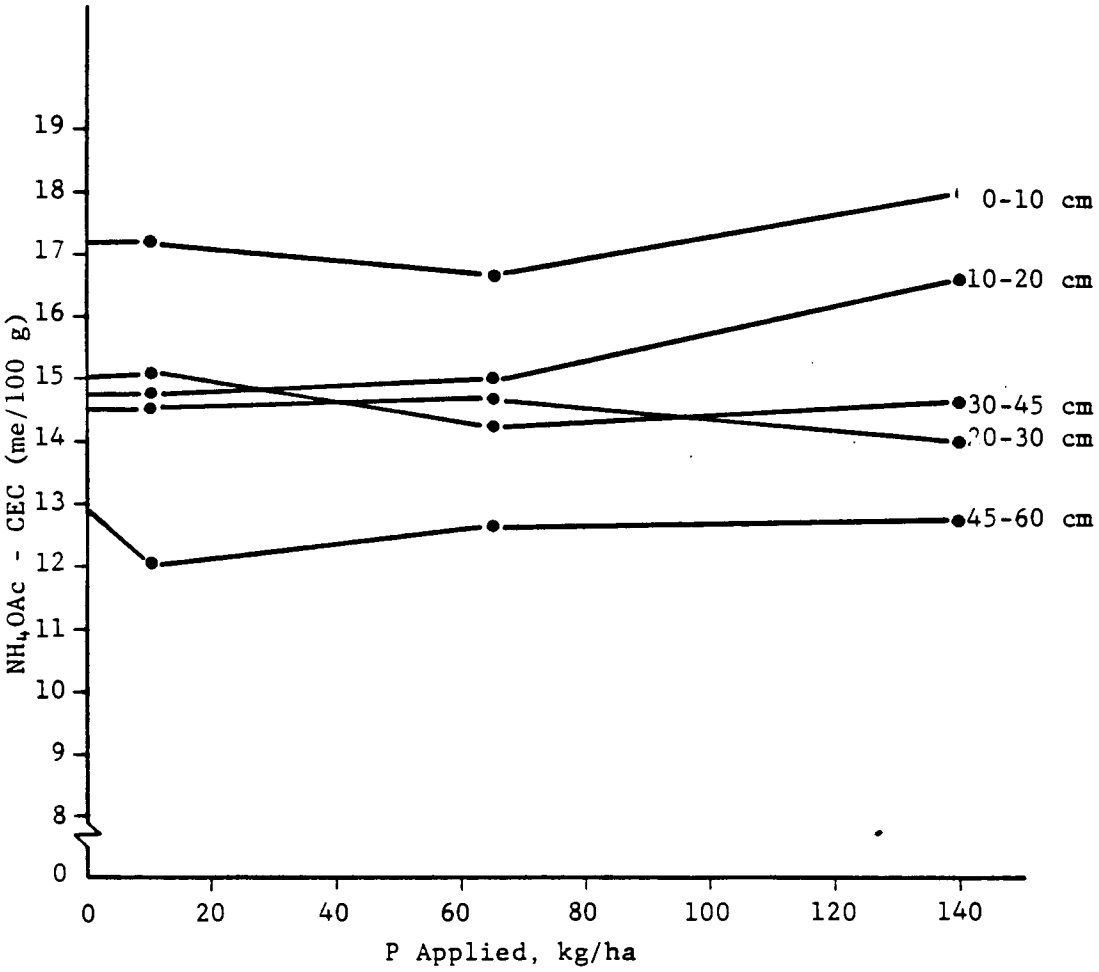


Fig. 4. Relationship between NH_4OAc - CEC and P applied for the Tropeptic Eutrustox at the Waipio Site

Table 9

Effect of P Fertilization on NH_4OAc - CEC* of a Tropeptic Eutrustox from Hawaii Waialua Site

Depth (cm)	P Applied, kg/ha			
	0	98	196	F***
	me/100 g			
0-15	19.00** a	19.24 a	19.76 a	22.58
15-30	16.72 abc	17.68 ab	17.25 ab	18.68
30-45	14.48 bc	14.58 bc	14.97 bc	16.73
45-60	13.23 c	13.36 c	13.74 c	14.63

* Average of 4 replicates

** Averages followed by the same letter are not significantly different from each other at the 5% level.

*** Samples taken from a fallow area

there was relatively little opportunity for much of the soil to react with the phosphorus since it was banded.

An interesting feature is the higher CEC values of the samples taken from the fallow field compared to those from the experimental plots. The increase is probably due to the higher organic matter content of the fallow area.

b. 1 N NH_4Cl - CEC. Figure 5 shows the relationship between CEC and the rates of P applied. As with NH_4OAc - CEC no significant differences in NH_4Cl - CEC were measured as a result of P application. The CEC values obtained by acetate displacement were consistently higher than those obtained by chloride displacement (Table 10). These results are consistent with those obtained with the Hydric Dystrandept.

It should be pointed out that the application of phosphate to variable-charge soils does not necessarily result in an increase in CEC. Much depends on the extent of sorption versus precipitation mechanisms. According to Stoop (1974), if all the P added is precipitated, the increase in CEC is likely to be nil or negligible. However, the experimental conditions under which this study was conducted do not allow determination of which of the above mechanisms predominated.

C. Effect of P Fertilization on Effective Cation Exchange Capacity (ECEC)

Throughout this text effective CEC is taken as the sum of 1 N NH_4OAc extractable bases plus 1 N KCl extractable Al and H, assuming Al to be present as the trivalent cation.

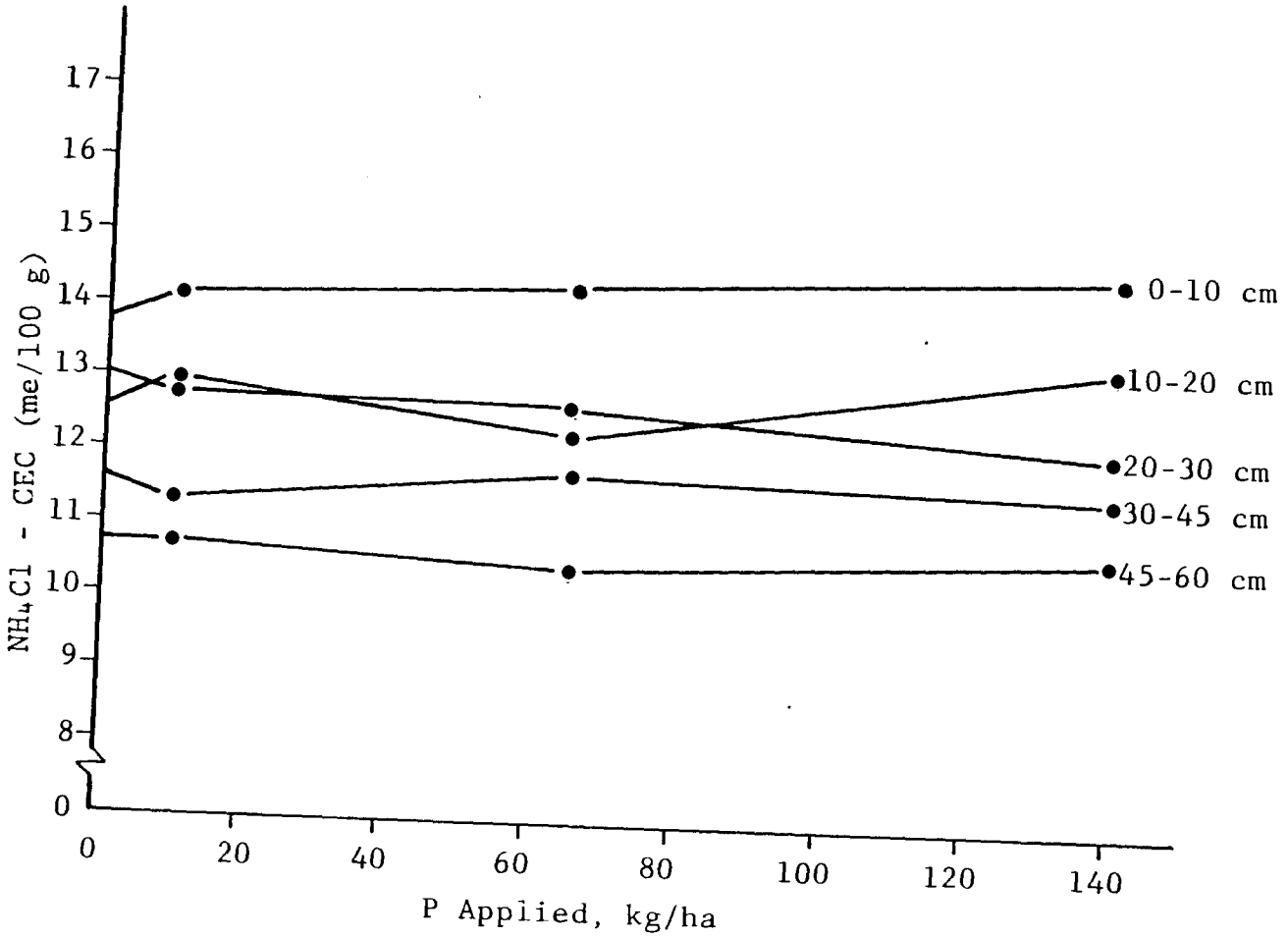


Fig. 5. Relationship between NH_4Cl - CEC and P applied for the Tropeptic Eutrustox at the Waipio site

Table 10

Effect of P Treatments and Soil Depth on the Ratio of NH_4OAc - CEC ÷ NH_4Cl - CEC of a Tropeptic Eutrustox from Hawaii Waipio Site

Depth (cm)	P Applied, kg/ha			
	0	10	65	140
0-10	1.24	1.22	1.16	1.25
10-20	1.17	1.15	1.23	1.40
20-30	1.11	1.17	1.16	1.16
30-45	1.28	1.35	1.20	1.32
45-60	1.18	1.01	1.03	1.22

The increase in negative charge due to high salt concentration and high pH of the extractant is not a factor in this determination.

1. Hydric Dystrandepts. Data of ECEC are presented in Tables 11 and 12. By way of contrast, neutral 1 N NH_4OAc - CEC and NH_4Cl - CEC were always greater than ECEC. ECEC was consistently higher for the highest level of P over the lower P level at all depths in the Hydric Dystrandept of the Kukaiau site, but only ECEC of the 0-10 cm layer was significantly (10% level) higher than those of the lower P rates. It was about 1.82 me/100 g soil higher. However, since phosphate was applied as treble superphosphate its Ca probably contributed to the increased ECEC. It should be recalled that NH_4OAc - CEC was significantly higher for both the 396 and 750 kg P/ha treatments, so apparently added P did increase CEC.

For the soil from the Philippines, increases in CEC due to P did not occur in the first 10 cm. However, as will be discussed later, this may be due to the fact that Mg and Ca were probably specifically adsorbed in the Stern layer. In effect, the amounts of Ca and Mg extracted from the low P area were much higher than those from the high P area.

2. Tropeptic Eutrustox. Although the observed differences in ECEC for the Waipio soil (Table 13) are not statistically significant, there is a trend towards higher ECEC with increasing rates of P applied. In all treatments ECEC gradually decreased with depth presumably because of the

Table 11

Effect of P Fertilization on the Effective Cation Exchange Capacity (ECEC)* of a Hydric Dystrandept from Hawaii Kukaiau Site

Depth (cm)	P Applied, kg/ha			
	0	40	396	750
	me/100 g			
0-10	5.35** efg	5.25 efg	5.93 cdefg	7.17 a
10-20	5.18 fg	5.30 efg	5.55 defg	5.70 defg
20-30	6.42 abcd	6.07 bcdef	6.85 abc	7.00 ab
30-45	4.99 f	5.77 defg	6.48 abcd	6.78 abc
45-60	5.86 cdfg	5.66 defg	5.95 cdefg	6.19 bcde

* Average of 3 replicates

** Averages followed by the same letter are not significantly different from each other at the 10% level.

Table 12

Effect of P on the Effective Cation Exchange Capacity (ECEC) of a Hydric Dystrandept from the Philippines

Depth (cm)	Low P Area	High P Area
	me/100 g	
0-10	6.29 b	6.04 bc
10-20	5.34 d	5.50 cd
20-30	6.38 b	5.18 d
30-45	5.26 d	7.47 a
45-60	5.03 d	6.12 b

Averages followed by the same letter are not significantly different from each other at the 5% level.

Table 13

Effect of P Fertilization on the Effective Cation Exchange Capacity (ECEC)* of a Tropeptic Eutrustox from Hawaii Waipio Site

Depth (cm)	P Applied, kg/ha			
	0	10	65	140
	me/100 g			
0-10	14.05** a	14.27 a	14.91 a	15.38 a
10-20	12.24 b	11.54 bcd	12.09 bc	12.50 b
20-30	11.29 bcde	10.31 def	10.55 cdefg	10.84 bcdef
30-45	9.64 efgh	9.37 fgh	9.87 defgh	9.22 fgh
45-60	9.29 fgh	8.60 h	9.07 h	8.88 h

* Average of 3 replicates

** Averages followed by the same letter are not significantly different from each other at the 10% level.

decrease in exchangeable acidity and exchangeable cations as well. Statistically significant differences in ECEC were not recorded for the soil from Waialua (Table 14).

This may be due, however, to the dilution of the fertilizer band into the sampled soil core. Again the samples from the fallow area gave a consistently higher ECEC than the experimental plots. This can be looked upon as an illustration of the effect of cultivation on the levels of exchangeable cations. It is well established that during the cropping period the levels of basic cations gradually decrease due to leaching and crop uptake and that the magnitude of these changes varies with soil properties.

Linear correlation coefficients for relationships among NH_4OAc - CEC, NH_4Cl - CEC, and ECEC were calculated for the Hydric Dystrandept and the Tropeptic Eutrustox. Then simple regression statistics were used to quantify these relationships. However, since there is no cause-effect relationship between the different parameters, NH_4OAc - CEC, NH_4Cl - CEC, and ECEC were referred to as X_1, X_2, and X_3, respectively. Therefore X_1, X_2, and X_3 were alternatively taken as independent and dependent variables in the regression analysis. Only one equation of each pair obtained is presented in Tables 15 and 16. An ideal "fit" between two extractants occurs when b_0 = 0 me/100 g, b_1 = 1, and r = 1.

For the Hydric Dystrandept (Table 15), a very weak, statistically nonsignificant relationship was found between NH_4OAc - CEC and ECEC on one hand, and NH_4Cl - CEC and ECEC

Table 14

Effect of P Fertilization on the Effective Cation Exchange Capacity (ECEC)* of a Tropeptic Eutrustox from Hawaii Waialua Site

Depth (cm)	P Applied, kg/ha			
	0	98	196	F***
	me/100 g			
0-15	6.55** abc	6.77 abc	7.34 ab	9.28
15-30	5.31 cd	4.86 d	5.38 cd	6.20
30-45	6.23 abcd	5.45 cd	5.96 bcd	9.16
45-60	7.25 ab	7.60 a	7.44 ab	9.21

* Average of 4 replicates

** Averages followed by the same letter are not significantly different from each other at the 5% level.

*** Samples taken from a fallow area

Table 15

Correlation and Regression Coefficients for the Various Methods of CEC Determination (Hydric Dystrandept--Kukaiau Site)

METHOD	MODEL†	b_0‡ (me/100 g)	b_1ǂ	r
1 N NH_4OAc - CEC	$X_1 = b_0 + b_1X_3$	35.68	1.587	0.195^{ns}
1 N NH_4Cl - CEC	$X_2 = b_0 + b_1X_3$	20.05	1.028	0.116^{ns}
1 N NH_4OAc - CEC	$X_1 = b_0 + b_1X_2$	24.58	0.786	0.859^{**}

† X_1 = NH_4OAc - CEC, X_2 = NH_4Cl - CEC, X_3 = ECEC

‡ b_0 = intercept regression coefficient

ǂ b_1 = slope regression coefficient

** = highly significant ($P < 0.01$)

ns = not significant

Table 16

Correlation and Regression Coefficients for the Various Methods of CEC Determination (Tropeptic Eutrustox--Waipio Site)

METHOD	MODEL†	b_0‡ (me/100 g)	b_1‡	r
1 N NH_4OAc - CEC	$X_1 = b_0 + b_1X_3$	7.90	0.636	0.702**
1 N NH_4Cl - CEC	$X_2 = b_0 + b_1X_3$	7.10	0.480	0.817**
1 N NH_4OAc - CEC	$X_1 = b_0 + b_1X_2$	2.41	1.015	0.653**

† X_1 = NH_4OAc - CEC, X_2 = NH_4Cl - CEC, X_3 = ECEC

‡ b_0 = intercept regression coefficient

‡ b_1 = slope regression coefficient

** = highly significant ($P < 0.01$)

on the other hand. However, a close relationship (r = 0.859**) between NH_4OAc and NH_4Cl - CEC was obtained. For the Tropeptic Eutrustox (Table 16), significant linear relationships were found between NH_4OAc - CEC and ECEC (r = 0.702**) on one hand, and NH_4Cl - CEC and ECEC (r = 0.817**) on the other hand. Moreover, NH_4OAc - CEC was closely related to NH_4Cl - CEC (r = 0.653**). When data from both soils were considered the following regression equations were obtained:

NH_4OAc - CEC = 64.70 - 4.03 ECEC (r = -0.789**)

NH_4Cl - CEC = 34.64 - 1.78 ECEC (r = -0.675**)

NH_4OAc - CEC = -4.83 + 1.808 NH_4Cl - CEC (r = 0.936**).

It follows that the introduction of data from both soils into the regression equations resulted in higher correlation coefficients than when regressions were performed separately for each soil. One possible explanation is the relatively greater range between the lowest and the highest CEC values as a result of combining data from both soils.

The CEC values obtained by acetate and chloride displacement confirm, for the Tropeptic Eutrustox and the Hydric Dystrandept, the conclusions reached by other workers (Van Raij and Peech, 1972; Gillman and Bell, 1976) that the use of solutions of high pH and ionic strength does not provide a realistic measurement of in situ CEC for soils with variable charge. Both methods make no allowance for the dependence of CEC on pH and solution ionic strength.

D. Effect of P Fertilization on the Distribution of NH_4OAc-Extractable Cations in the Soil Profile

The availability to plants of cationic nutrients depends, among other things, on their distribution in the soil profile. Studies aimed at determining the fate of cationic nutrients constitute an important aspect of soil fertility. In order to illustrate the distribution of exchangeable cations in the soil profile only data obtained with NH_4OAc will be used since NH_4Cl showed similar patterns.

1. Hydric Dystrandepts. For the Hydric Dystrandept of the Kukaiau site the effect of phosphate fertilization on the exchangeable Ca, Mg, K, and Na in the profile is depicted in Figures 6, 7, 8, and 9, respectively. Exchangeable CA increased substantially to a depth of 60 cm as the rates of phosphate increased. This, however, does not necessarily indicate that Ca was readily leached, but possibly that the increase was caused by the contribution of Ca from applied treble superphosphate. Leaching of Ca beyond the 60 cm depth appeared to be greatest in the 0 and 40 kg P/ha treatments. Data obtained with Mg, K, and Na (Figures 7, 8, and 9, respectively) suggest a slightly higher accumulation of these cations at lower depths in the partial control. Despite the fact that previous greater dry matter production in the high P treatment certainly resulted in greater Mg, K, and Na removal, the levels of these exchangeable bases in the top 10 cm generally remained higher than those of the same nutrients in the partial control. Since

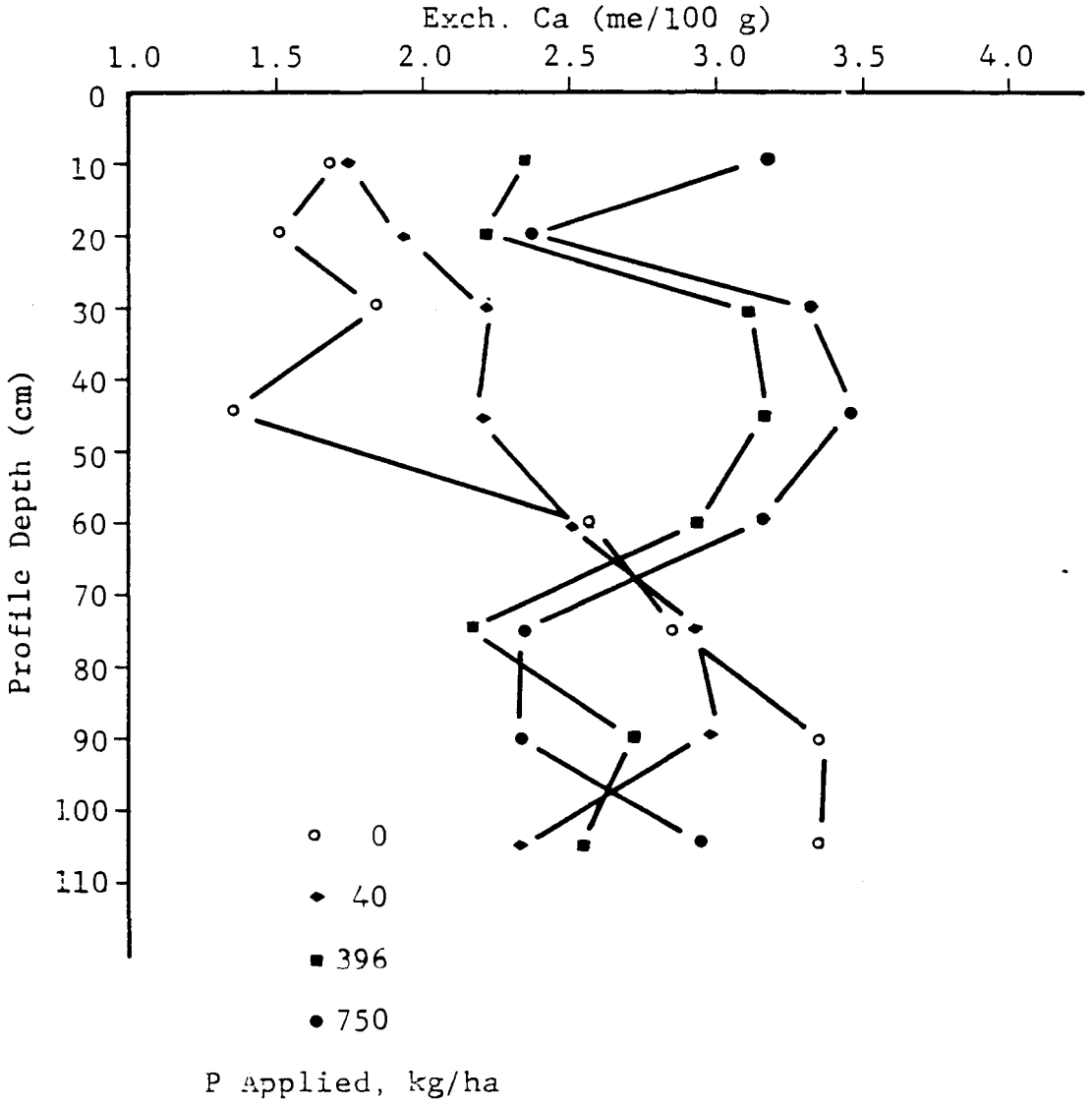


Fig. 6. Effect of rates of applied P on exchangeable Ca at different soil depths (Hydric Dystrandept--Kukaiau Site)

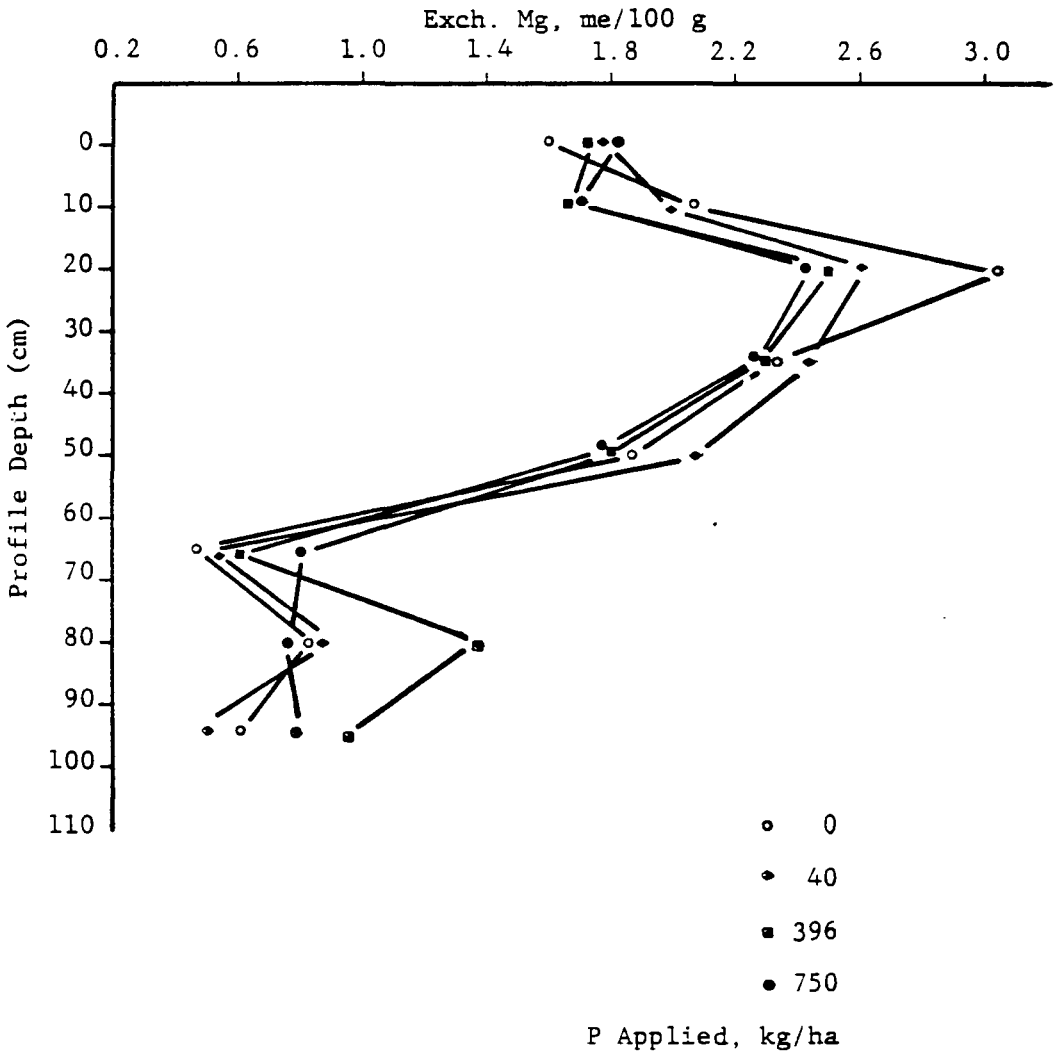


Fig. 7. Effect of rates of applied P on exchangeable Mg at different soil depths (Hydric Dystrandept-- Kukaiau Site)

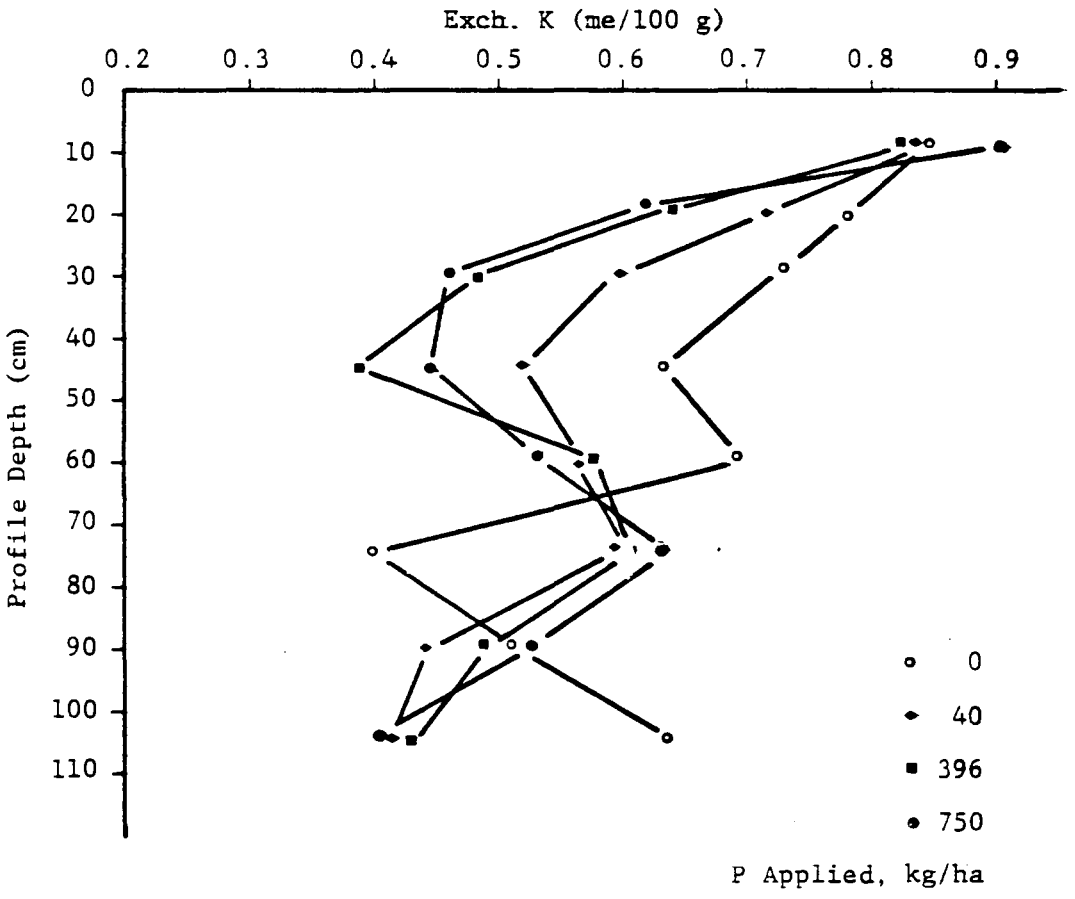


Fig. 8. Effect of rates of applied P on exchangeable K at different soil depths (Hydric Dystrandept--Kukaiau Site)

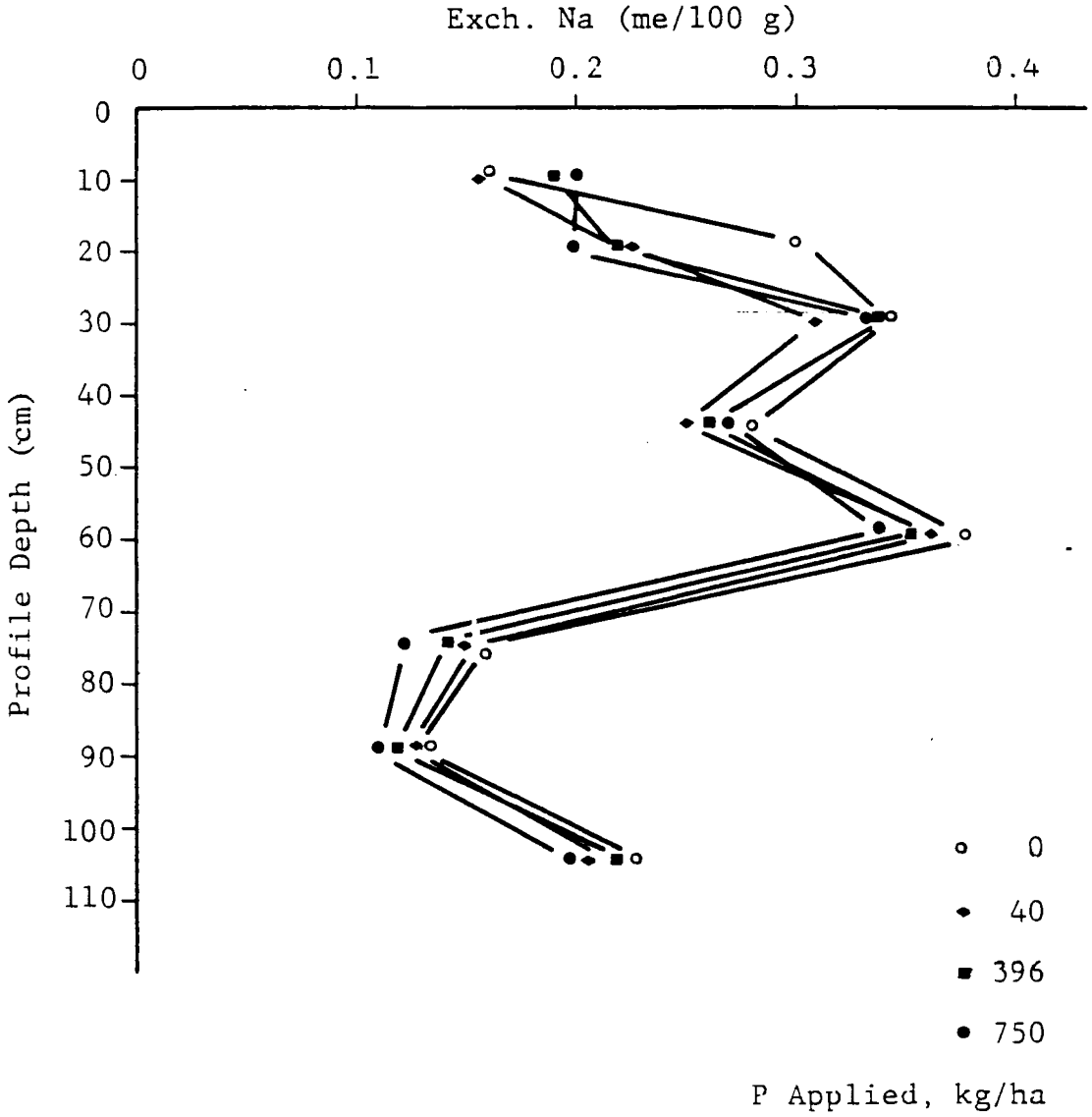


Fig. 9. Effect of rates of applied P on exchangeable Na at different soil depths (Hydric Dystrandept--Kukaiau Site)

Mg and K were applied equally to all plots, the differences in exchangeable Mg and K found in the top 10 cm may be looked upon as the result of an increase in the capacity of the soil to retain cationic nutrients against leaching. These results corroborate those reported by Gillman and Fox (1980) on the effect of long-term P application on variable-charge soils from Hawaii.

The striking feature for the Hydric Dystrandept from the Philippines (Table 17) is that the level of exchangeable Ca is much higher in the low P than in the high P area in the 0 to 10 cm layer. The same trend is evident for Mg even at a depth of 30 cm. One possible explanation for the observed differences is the suggestion by Chan et al. (1979) that Mg and Ca become nonexchangeable through specific adsorption of the hydroxy cations into the Stern layer. Moreover, since Mg has a greater tendency than Ca to exist in the hydroxyl form, $MgOH^+$ (Chan et al, 1979), specific adsorption of Mg is expected to be greater. This may explain why exchangeable Mg, unlike Ca, was consistently lower to a depth of 30 cm in the high P area than in the low one. These results are in agreement with those reported by Wann and Uehara (1978). They found that the quantity of divalent cations extracted with 1 N NH_4OAc decreased with increasing phosphorus application.

2. Tropeptic Eutrustox. Figures 10, 11, 12, and 13 illustrate the effect of P application on the distribution of exchangeable Ca, Mg, K, and Na, respectively, in the

Table 17

Effect of P on NH_4OAc-Extractable Cations of a Hydric Dystrandept from the Philippines

Depth (cm)	Low P Area				High P Area			
	Ca	Mg	K	Na	Ca	Mg	K	Na
	me/100 g				me/100 g			
0-10	3.18	1.37	0.20	0.26	2.76	0.90	0.22	0.34
10-20	2.22	1.01	0.30	0.32	2.94	0.74	0.24	0.30
20-30	2.99	1.42	0.38	0.50	2.24	0.76	0.21	0.28
30-45	2.52	1.40	0.18	0.39	4.55	1.65	0.22	0.30
45-60	2.44	1.30	0.16	0.36	3.50	1.42	0.14	0.28
$LSD_{0.05}$	0.51	0.26	0.05	0.04	0.51	0.26	0.05	0.04

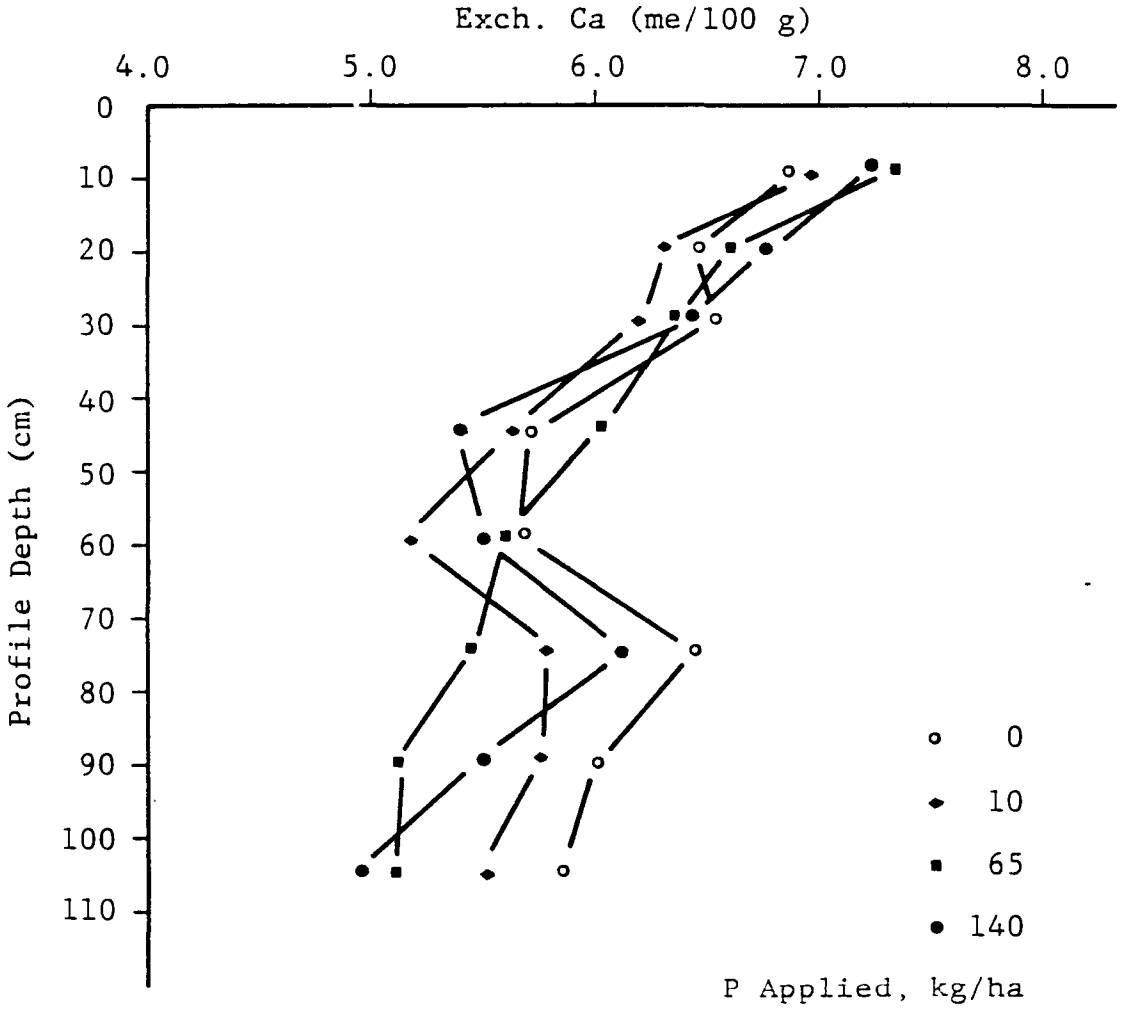


Fig. 10. Effect of rates of applied P on exchangeable Ca at different soil depths (Tropeptic Eutrustox--Waipio Site)

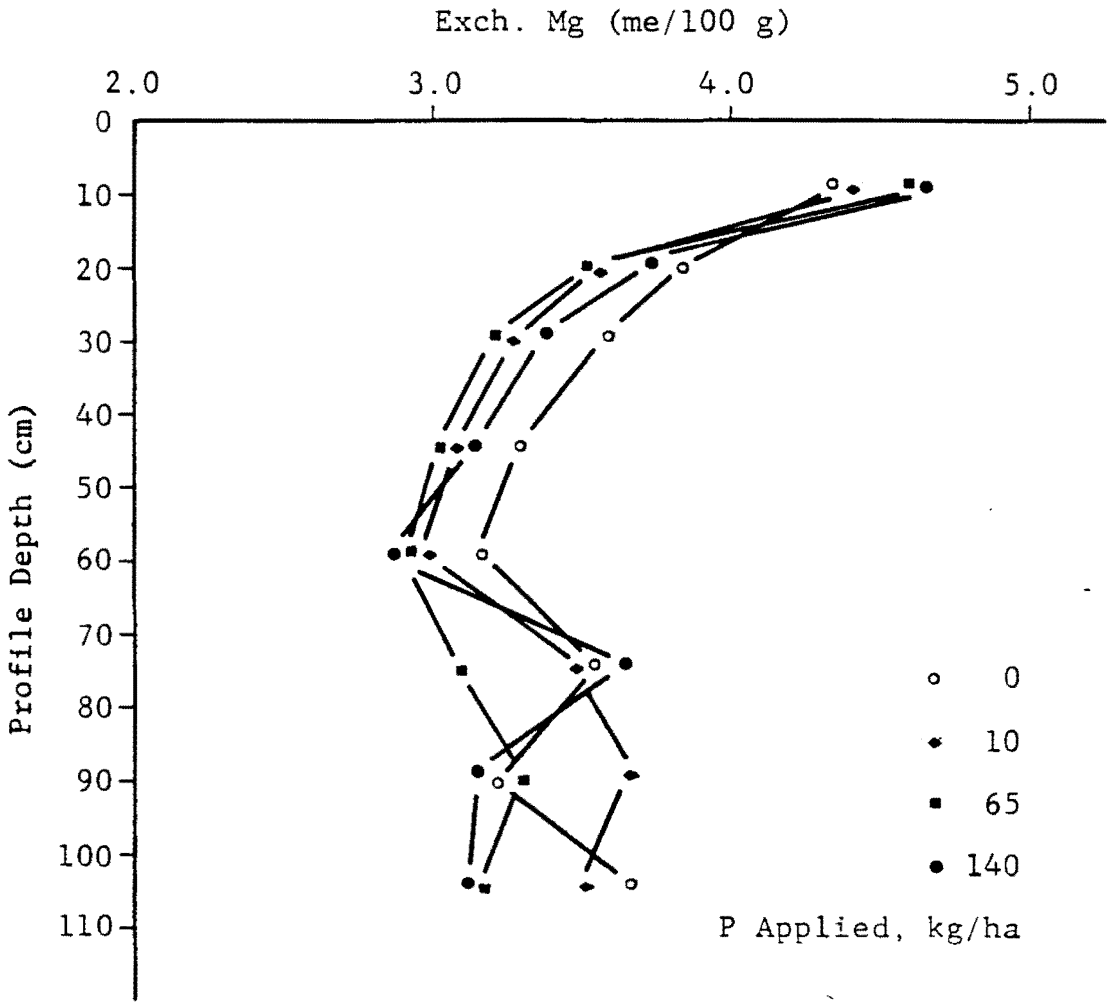


Fig. 11. Effect of rates of applied P on exchangeable Mg at different soil depths (Tropeptic Eutrustox--Waipio Site)

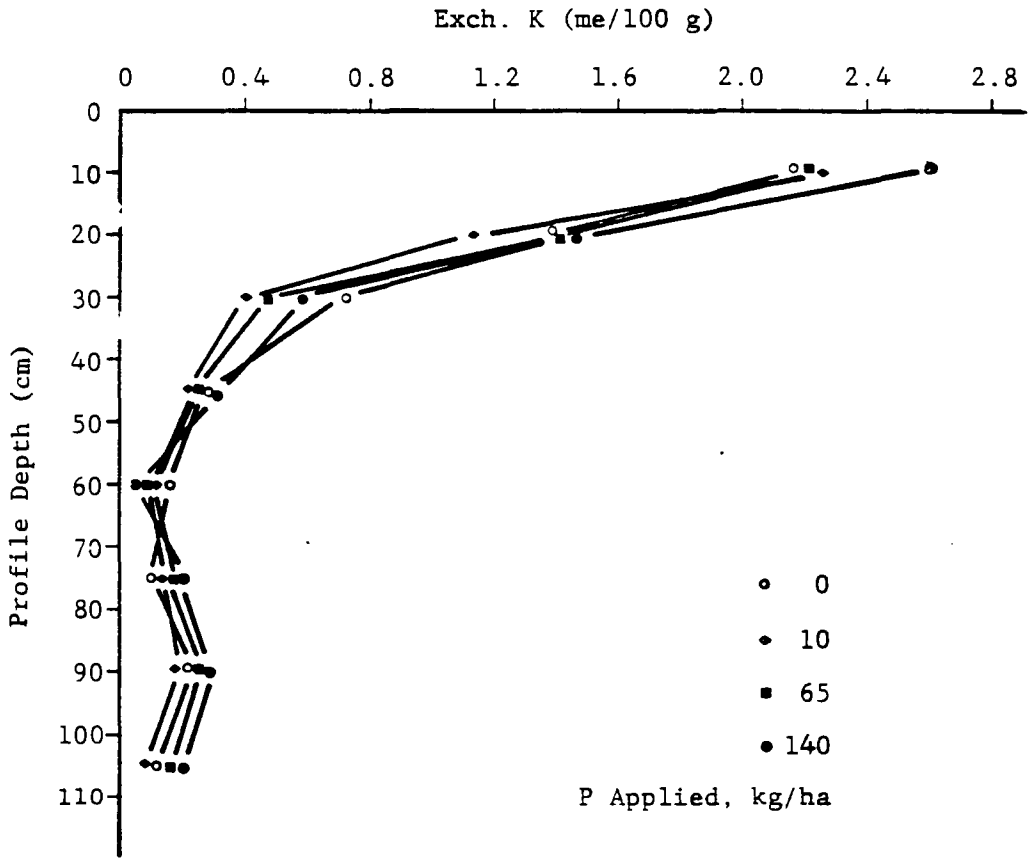


Fig. 12. Effect of rates of applied P on exchangeable K at different soil depths (Tropeptic Eutrustox--Waipio Site)

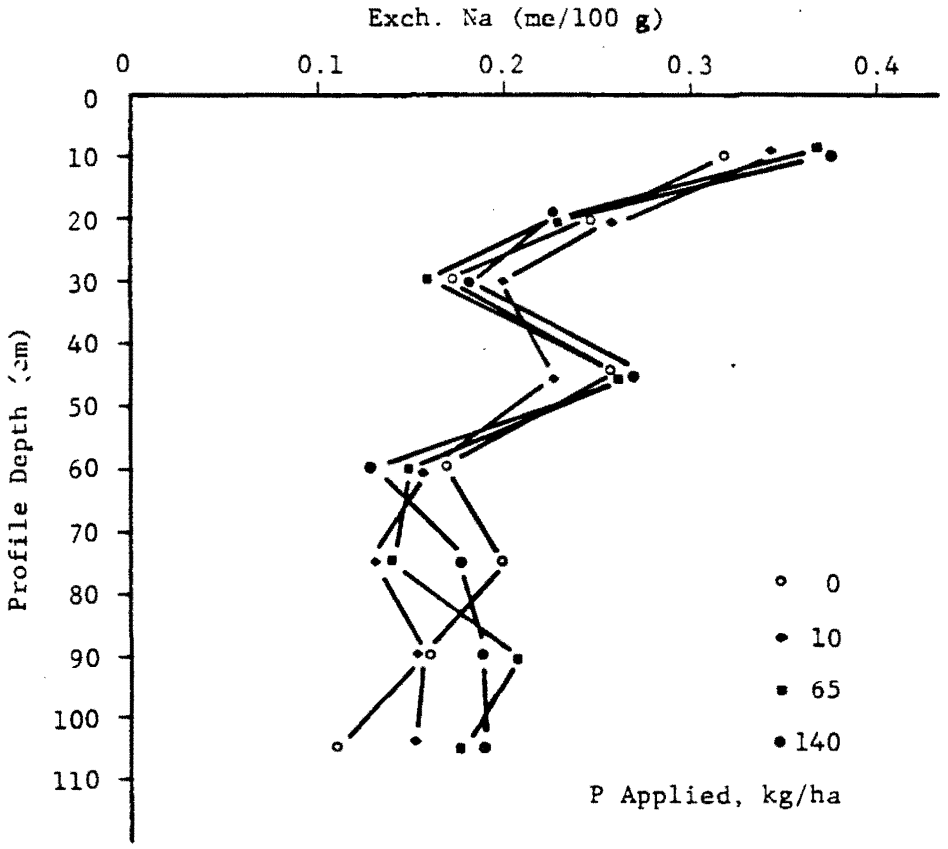


Fig. 13. Effect of rates of applied P on exchangeable Na at different soil depths (Tropeptic Eutrustox--Waipio Site)

profile of the Tropeptic Eutrustox from Waipio. The general trend shown in these figures is that the level of exchangeable cations in the 0 to 10 cm layer increased slightly with increasing rates of applied P. This occurred in spite of the fact that greater amounts of cationic nutrients were removed from plots which received high rates of P as a result of greater crop production. On the other hand, more leaching of Ca and Mg generally occurred in the 0 and 10 kg P/ha treatments. An interesting feature of these graphs is that the level of these four exchangeable cations decreased with depth and the decrease was most drastic in the case of potassium.

The distribution of exchangeable Ca, Mg, K, and Na in the profile of the Waialua site is depicted in Figures 14, 15, 16, and 17, respectively.

Phosphate application had no significant effect on the distribution of exchangeable cations in the soil profile. However, there was a trend for the Ca and Mg levels in the 0-30 cm depth to be higher than those for the treatment without P application. In all experimental plots exchangeable Ca, Mg, and Na increased with depth, whereas exchangeable K gradually decreased with depth. The higher K content in the 0-15 cm layer than in the underlying layers, however, may be the result of potassium application. The striking feature of these figures is the large difference in the level of exchangeable cations between the samples taken from the experimental plots and those from the fallow area. A possible

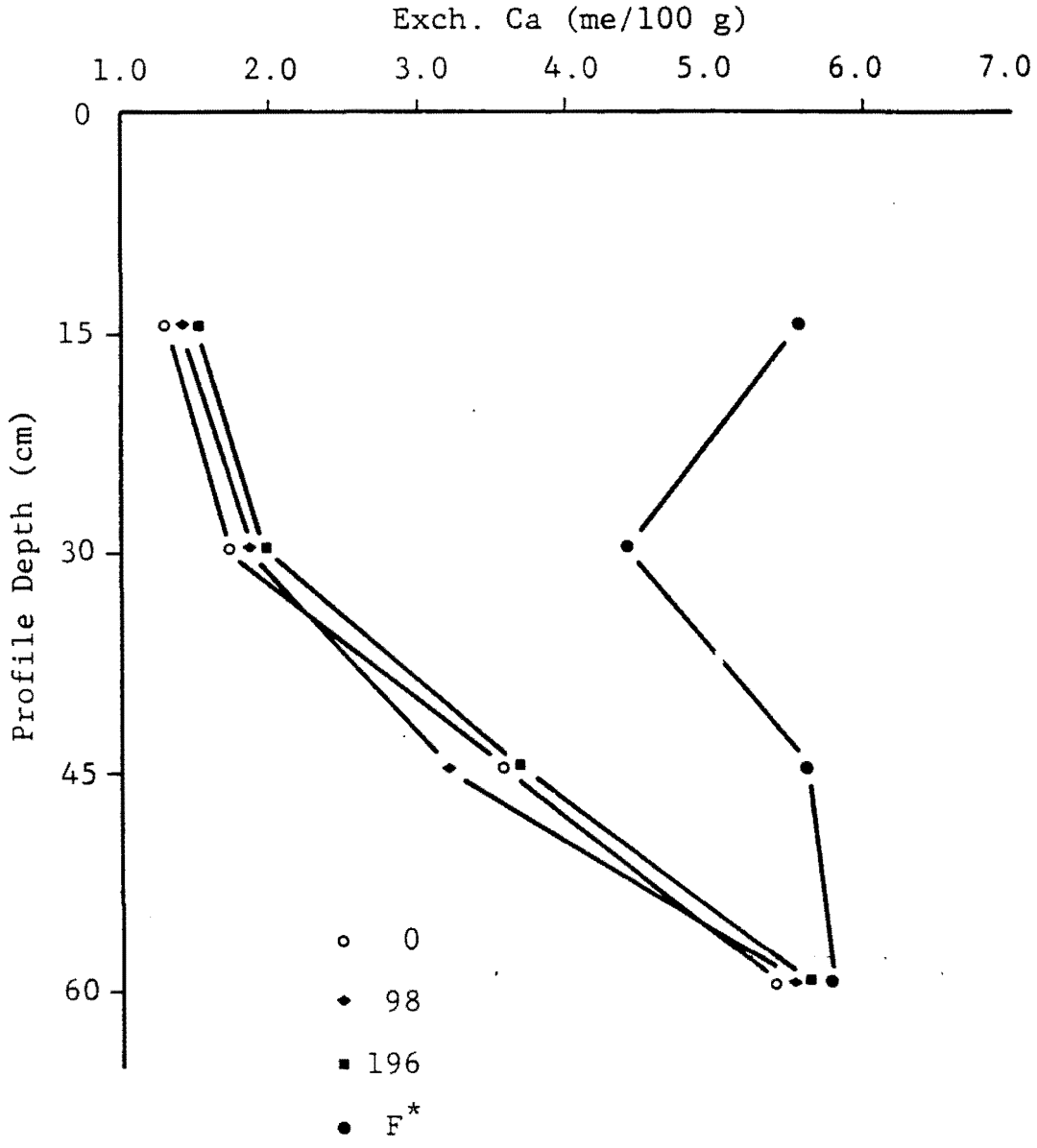


Fig. 14. Effect of rates of applied P on exchangeable Ca at different soil depths (Tropeptic Eutrustox-Waialua Site)

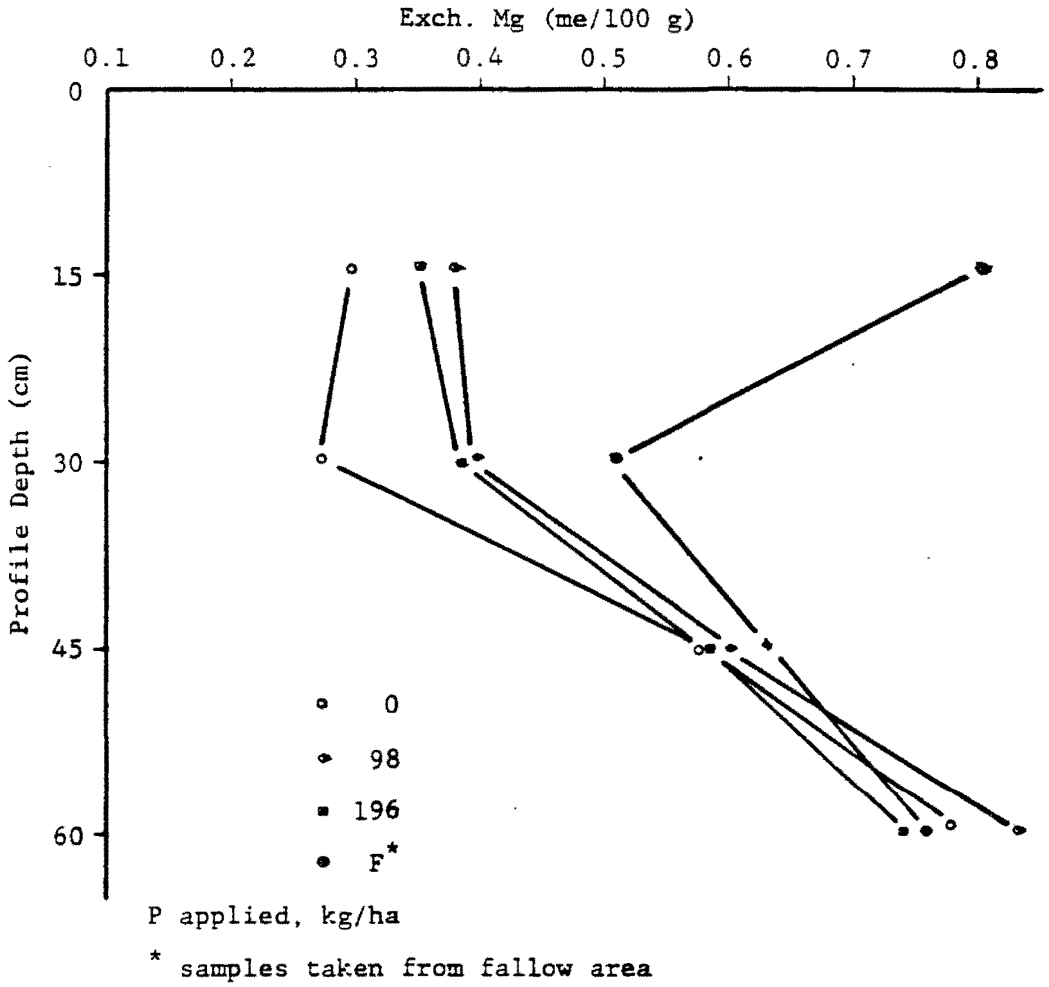


Fig. 15. Effect of rates of applied P on exchangeable Mg at different soil depths (Tropeptic Eutrustox--Waialua Site)

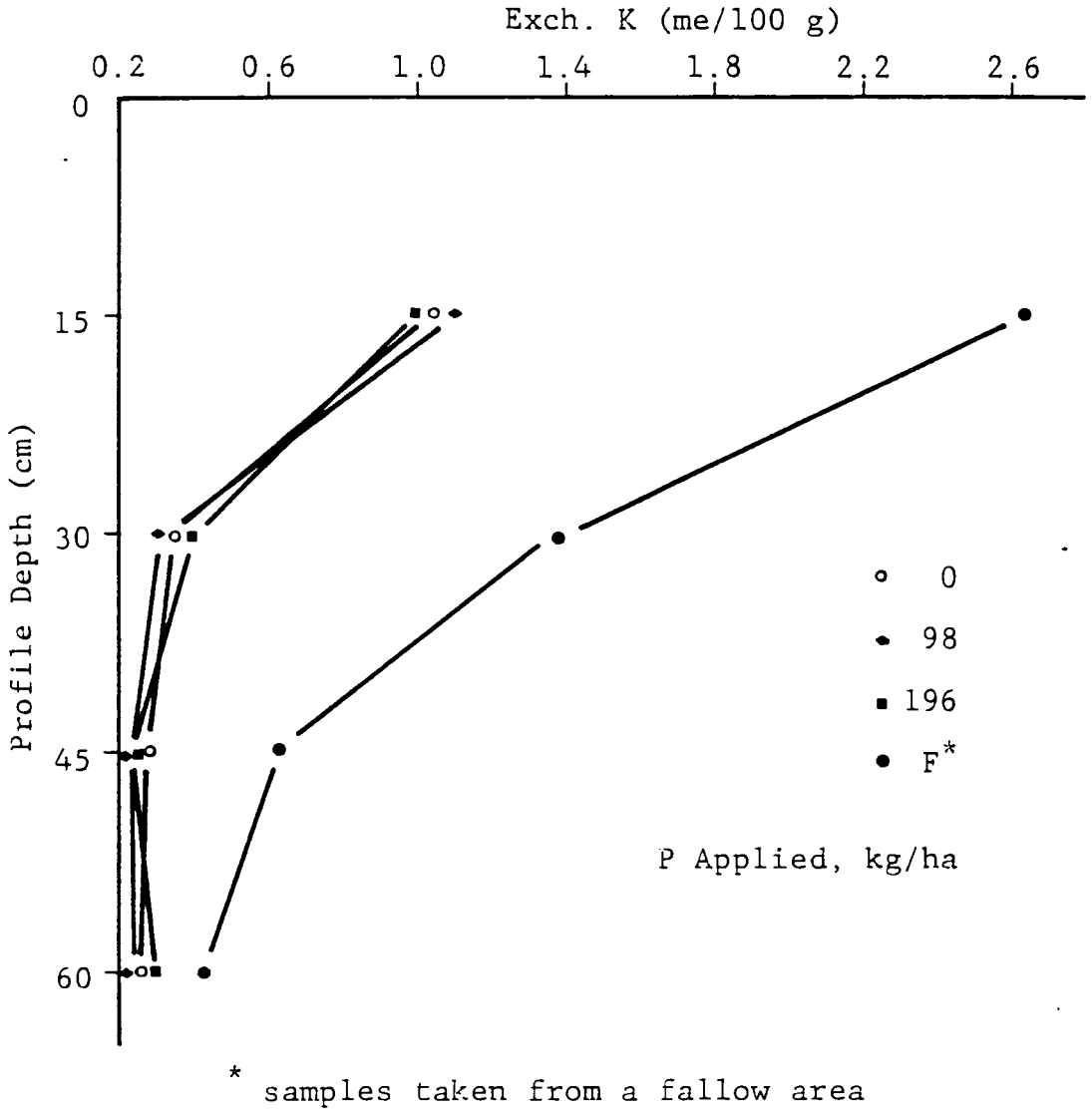


Fig. 16. Effect of rates of applied P on exchangeable K at different soil depths (Tropeptic Eutrustox--Waialua Site)

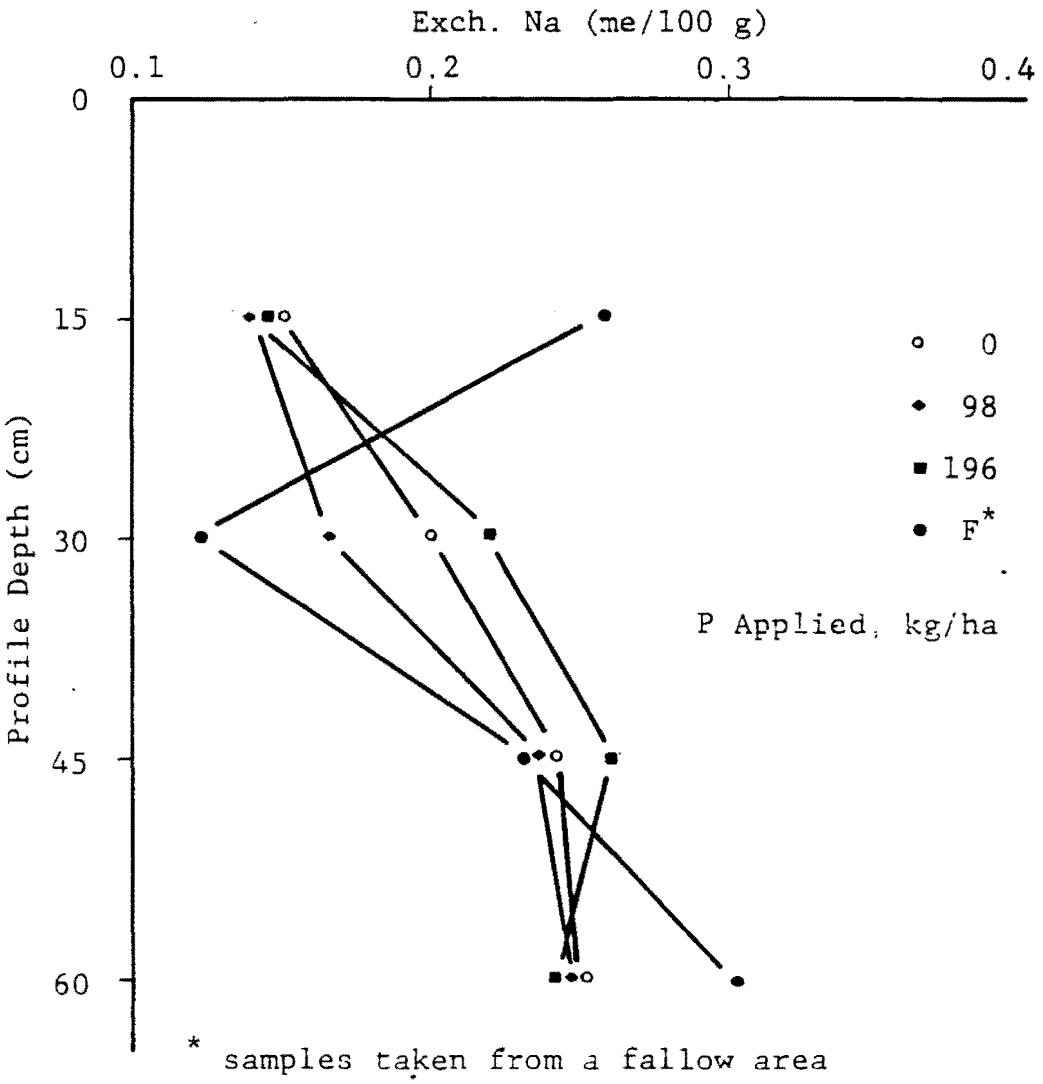


Fig. 17. Effect of rates of applied P on exchangeable Na at different soil depths (Tropeptic Eutrustox--Waialua Site)

explanation is that with cultivation the level of basic cations gradually decreased due to leaching and crop uptake.

E. Exchangeable Bases Extracted by the NH_4OAc, NH_4Cl, and EUF Methods

In order to ascertain the reliability of fertilizer recommendations the evaluation of the nutrient status in the soil should be made by precise methods. Numerous methods for determining exchangeable cations have been devised. Each method, however, has its inherent shortcomings and the reliability of many of them is yet to be tested. Electro-ultrafiltration (EUF) is a relatively recent development in soil testing and it is important to evaluate it fully by comparison with conventional soil testing methods. This will be done in this part of the thesis using data obtained with selected soil samples taken before planting which were also extracted with NH_4OAc and NH_4Cl.

1. Hydric Dystrandept. Exchangeable cations determined by the three methods are shown in Table 18. The quantities of Ca, Mg, K, and Na obtained in the first six aliquots (0-30 minutes) in the EUF method were summed and considered to represent the exchangeable Ca, Mg, K, and Na. According to Ne'meth (1982) this fraction indicates the level of nutrients which can most easily be made available to plant roots in the course of a vegetative period. It can be gathered from Table 18 that the quantity of divalent cations extracted by NH_4Cl was consistently higher than that determined by NH_4OAc. On the other hand, NH_4OAc extracted more K

Table 18

Exchangeable Bases Extracted by the NH_4OAc, NH_4Cl, and EUF Methods
Hydric Dystrandept
Kukaiau Site

Depth (cm)	P Applied, kg/ha					
	0			750		
	NH_4OAc	NH_4Cl	EUF	NH_4OAc	NH_4Cl	EUF
	Ca (me/100 g)					
0-10	1.69	2.87	0.63	3.18	4.78	0.84
10-20	1.52	2.66	0.40	2.34	4.27	0.90
$LSD_{0.1}$	0.50	0.56	0.34	0.50	0.56	0.34
	Mg (me/100 g)					
0-10	1.60	1.69	0.37	1.80	1.81	0.44
10-20	2.07	2.01	0.40	1.69	1.66	0.39
$LSD_{0.1}$	0.38	0.53	0.29	0.38	0.53	0.29
	K (me/100 g)					
0-10	0.85	0.76	0.24	0.91	0.82	0.28
10-20	0.78	0.72	0.21	0.62	0.62	0.20
$LSD_{0.1}$	0.18	0.20	0.16	0.18	0.20	0.16
	Na (me/100 g)					
0-10	0.16	0.19	0.09	0.20	0.22	0.13
10-20	0.30	0.25	0.09	0.20	0.24	0.12
$LSD_{0.1}$	0.14	0.12	0.06	0.14	0.12	0.06

than NH_4Cl. The quantities of EUF - CA, Mg, K, and Na desorbed within 30 minutes at 20°C were consistently lower than the quantities of these bases extracted by NH_4Cl and NH_4OAc. Differences in the levels of exchangeable bases determined by EUF between the partial control and the highest P treatment were not statistically significant (10% level) except for Ca at the 10-20 cm depth. Likewise, the only significant difference in the levels of exchangeable bases extracted by NH_4OAc and NH_4Cl was found for exchangeable Ca between the low and high P treatments.

The relationship between exchangeable cations determined by the NH_4OAc, NH_4Cl, and EUF methods and P application is depicted in Figure 18. An assumption was made that there is a change in exchangeable cations due to P application. This, however, may not necessarily be true. The slopes of these curves indicate the change in the level of a given cation with a unit change in applied P. This in turn can be looked upon as an estimate of the sensitivity of the methods to the change in the levels of exchangeable cations. It can be gathered from Figure 18 that NH_4Cl showed the greatest change in exchangeable Ca per unit change in applied P. It was followed closely by NH_4OAc and EUF appeared to be the least sensitive of the three methods. For Mg, K, and Na the NH_4OAc, NH_4Cl, and EUF curves were almost parallel, suggesting that the three methods were equally sensitive to the changes in exchangeable Mg, K, and Na.

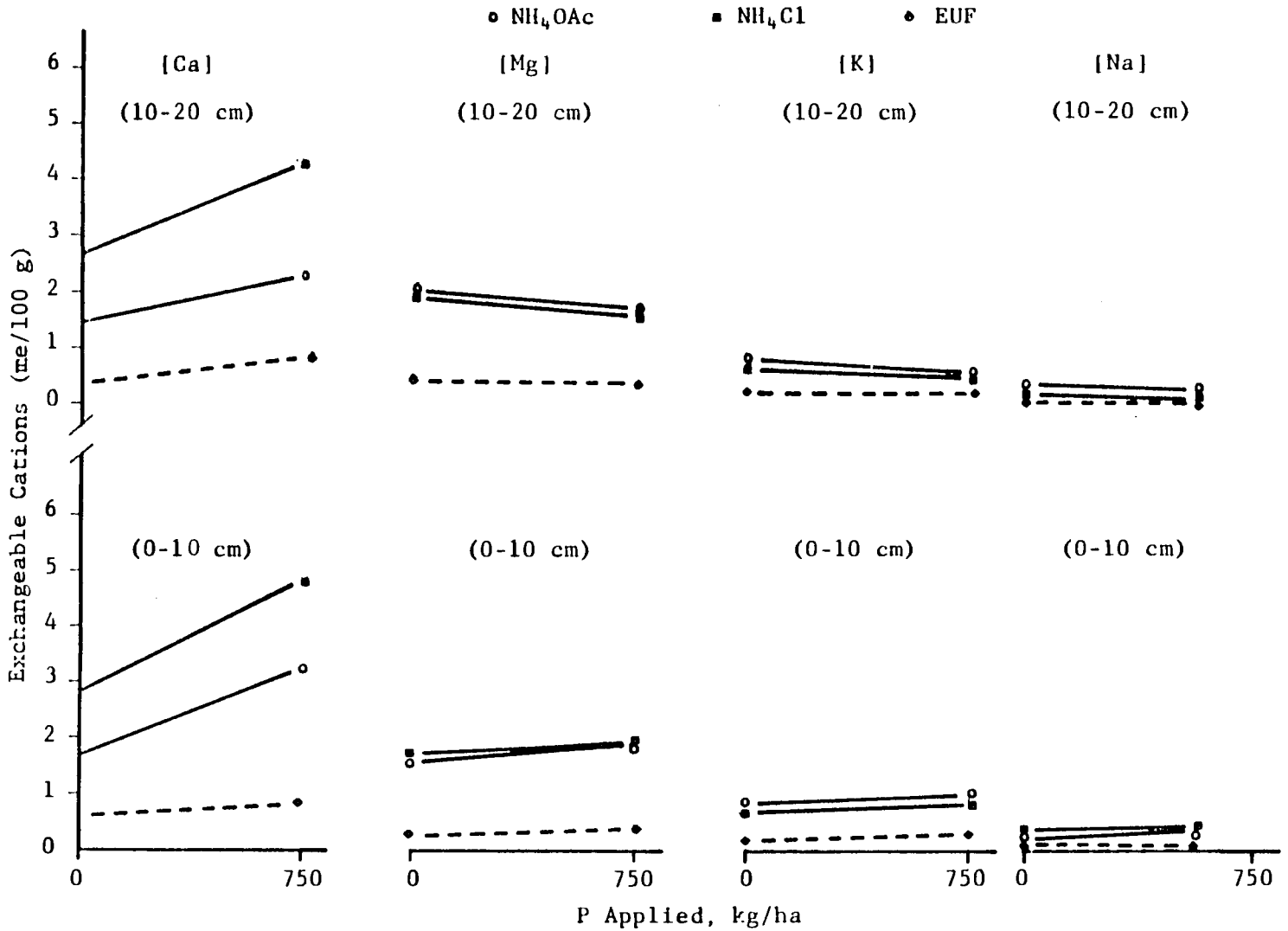


Fig. 18. Exchangeable bases extracted by the NH_4OAc, NH_4Cl and EUF methods at two levels of applied P (Hydric Dystrandept--Kukaiau Site)

Three EUF fractions, herein referred to as EUF_I, EUF_{II}, and EUF_{III} (Table 19), were obtained during the electroultrafiltration process. EUF_I is the fraction collected after 10 minutes at 20°C (5 minutes at 50 volts plus 5 minutes at 200 volts). According to Ne'meth (1979) this fraction is closely related to the nutrient concentration of the soil solution. EUF_{II} is the fraction extracted within 20 minutes (from 10 to 30 minutes) at 200 volts and 20°C. EUF_{III}, which is the fraction released between 30 and 35 minutes at 80°C, characterizes the soils buffering capacity. The higher the values of EUF_{III} the better the maintenance of the soil solution concentrations in the course of the vegetative period.

For Ca and Mg, the amounts of EUF_{II} were higher than those of EUF_I and EUF_{III}. The trend was less evident for Na and K. The values of EUF_I, which are closely related to cation concentrations in the soil solution, were slightly higher for Ca, Mg, and K in the high P treatment than in the partial control. These differences, however, were not statistically significant at the 10% level. On the other hand, Ca and Mg reserves (EUF_{III}) in the 0 to 10 cm layer were significantly higher in the high P treatment. This may be due to the fact that with increased CEC as a result of P application, leaching of divalent cations was retarded.

2. Tropeptic Eutrustox. The trends recorded for the Hydric Dystrandept were observed for the Tropeptic Eutrustox (Tables 20 and 21), viz., NH_4Cl extracted more divalent

Table 19

EUF-Extracted Cations from the Hydric Dystrandept

Depth (cm)	P Applied, kg/ha					
	0			750		
	Fractions Extracted			Fractions Extracted		
	EUF_I	EUF_{II}	EUF_{III}	EUF_I	EUF_{II}	EUF_{III}
	Ca (me/100 g)					
0-10	0.17	0.46	0.30	0.26	0.58	0.44
10-20	0.14	0.36	0.22	0.27	0.63	0.42
$LSD_{0.1}$	0.14	0.13	0.13	0.14	0.13	0.13
	Mg (me/100 g)					
0-10	0.16	0.21	0.06	0.19	0.25	0.11
10-20	0.14	0.26	0.06	0.15	0.24	0.08
$LSD_{0.1}$	0.04	0.09	0.04	0.04	0.09	0.04
	K (me/100 g)					
0-10	0.12	0.12	0.08	0.14	0.14	0.10
10-20	0.12	0.09	0.06	0.10	0.10	0.06
$LSD_{0.1}$	0.09	0.07	0.04	0.09	0.07	0.04
	Na (me/100 g)					
0-10	0.05	0.04	0.02	0.08	0.05	0.04
10-20	0.06	0.03	0.01	0.08	0.04	0.04
$LSD_{0.1}$	0.02	0.02	0.02	0.02	0.02	0.02

Table 20

Exchangeable Bases Extracted by the NH_4OAc, NH_4Cl, and EUF Methods
Tropeptic Eutrustox
Waipio Site

Depth (cm)	P Applied, kg/ha					
	0			140		
	NH_4OAc	NH_4Cl	EUF	NH_4OAc	NH_4Cl	EUF
	Ca (me/100 g)					
0-10	6.88	7.19	0.22	7.30	7.28	0.23
10-20	6.45	7.10	0.24	6.78	7.11	0.23
$LSD_{0.1}$	1.28	1.52	0.17	1.28	1.52	0.17
	Mg (me/100 g)					
0-10	4.34	4.62	0.17	4.66	4.94	0.16
10-20	3.86	4.20	0.17	3.74	4.23	0.16
$LSD_{0.1}$	0.50	0.52	0.06	0.50	0.52	0.06
	K (me/100 g)					
0-10	2.18	1.35	0.34	2.65	1.54	0.34
10-20	1.40	0.95	0.25	1.45	0.92	0.21
$LSD_{0.1}$	0.24	0.25	0.09	0.24	0.25	0.09
	Na (me/100 g)					
0-10	0.32	0.24	0.32	0.38	0.28	0.38
10-20	0.25	0.15	0.28	0.23	0.15	0.33
$LSD_{0.1}$	0.08	0.07	0.02	0.08	0.07	0.02

Table 21

Exchangeable Bases Extracted by the
NH_4OAc and EUF Methods
Tropeptic Eutrustox
Waialua Site

Rates of P (kg/ha)	Methods							
	EUF				NH_4OAc			
	Ca	Mg	K	Na	Ca	Mg	K	Na
	me/100 g							
0	0.51[a]	0.30[b]	0.21[c]	0.15[d]	1.28[a]	0.30[b]	1.06[c]	0.15[d]
196	0.59[a]	0.26[b]	0.20[c]	0.14[d]	1.34[a]	0.35[b]	1.03[c]	0.14[d]

Averages for the same nutrient followed by the same letter are not significantly different from each other. ($P < 0.10$)

cations than NH_4OAc, whereas the reverse was true for the quantities of exchangeable potassium and sodium extracted. Again, the EUF fraction extracted within 30 minutes at 20°C was extremely low compared with NH_4Cl- and NH_4OAc-extractable bases. Na, however, was an exception.

It is interesting to note that EUF Ca and Mg values were higher in the Hydric Dystrandept than in the Tropeptic Eutrustox, although the reverse was found for NH_4OAc and NH_4Cl extractable Ca and Mg. On the other hand, EUF K and Na values were higher in the Tropeptic Eutrustox than in the Hydric Dystrandept. The reason for this is not clear. It is well established, however, that the course of EUF depends, among other things, on the content and type of humus and the anion concentration of the soil solution. Moreover, since lime was applied in the Hydric Dystrandept three weeks before soil samples were taken, this may have affected the EUF Ca and Mg levels.

The relationship between exchangeable Ca, Mg, K, and Na determined by the three methods and P application is depicted in Figure 19. For Ca the trends recorded for the Hydric Dystrandept were observed for the Tropeptic Eutrustox, viz., NH_4Cl showed the highest change in exchangeable Ca per unit change in applied P. Again for Mg, K, and Na the NH_4OAc, NH_4Cl, and EUF curves were almost parallel. The marked difference in level of Ca and Mg extracted by NH_4Cl and NH_4OAc relative to that extracted by EUF is clearly evident in this figure.

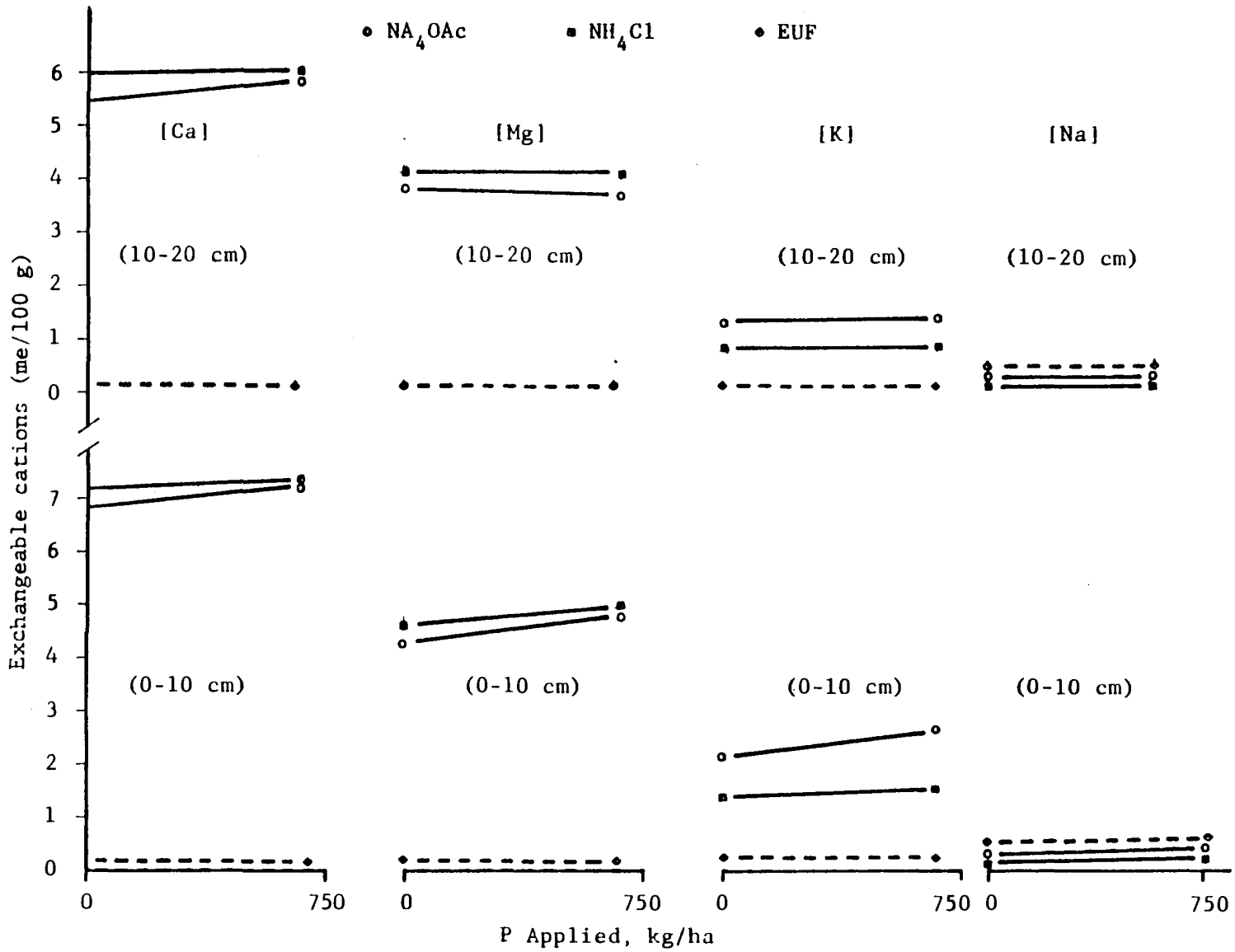


Fig. 19. Exchangeable bases extracted by NH_4OAc, NH_4Cl, and EUF methods at two levels of applied P (Tropeptic Eutrustox--Waipio Site)

The three extracted EUF fractions are presented in Tables 22 and 23. As for the Hydric Dystrandept, the amounts of EUF_{II} Ca, Mg, and even K were higher than those for EUF_I and EUF_{III} for the same bases. The rates of phosphate had no significant effect on the nutrient concentrations in the soil solution as is evident from EUF_I values.

By way of contrast, the Ca and Mg values of EUF_I were lower in the Tropeptic Eutrustox than in the Hydric Dystrandept, whereas the reverse was true for K and Na. This is the same pattern noted above.

Correlation and regression coefficients were calculated for the linear regression of cations extracted by NH_4OAc with the same cations extracted by NH_4Cl. On the other hand, NH_4OAc and NH_4Cl extractable cations were regressed upon the same cations determined by EUF. However, since there is no cause-effect relationship between the different parameters, NH_4OAc, NH_4Cl and EUF were referred to as X_1, X_2, and X_3, respectively. An ideal "fit" between two extractants occurs when $b_0 = 0$ me/100 g, $b_1 = 1$, $r = 1$. Since the number of samples from individual soils was relatively small (total of 8 samples) data from the Tropeptic Eutrustox and the Hydric Dystrandept were combined in the regression analysis. Table 24 shows that exchangeable bases (Ca, Mg, K) found in the NH_4OAc extract were closely related to their NH_4Cl counterparts. For Na, however, the relationship was not very close.

Table 22

EUF-Extracted Cations from the Tropeptic Eutrustox
Waipio Site

Depth (cm)	P Applied, kg/ha					
	0			140		
	Fractions Extracted			Fractions Extracted		
	EUF_I	EUF_{II}	EUF_{III}	EUF_I	EUF_{II}	EUF_{III}
	Ca (me/100 g)					
0-10	0.06	0.16	0.14	0.06	0.17	0.12
10-20	0.06	0.18	0.15	0.07	0.16	0.13
$LSD_{0.1}$	0.04	0.09	0.08	0.04	0.09	0.08
	Mg (me/100 g)					
0-10	0.05	0.12	0.06	0.04	0.12	0.05
10-20	0.04	0.13	0.06	0.04	0.12	0.06
$LSD_{0.1}$	0.02	0.06	0.04	0.02	0.06	0.04
	K (me/100 g)					
0-10	0.12	0.22	0.17	0.12	0.22	0.18
10-20	0.09	0.16	0.12	0.07	0.14	0.12
$LSD_{0.1}$	0.06	0.09	0.04	0.06	0.09	0.04
	Na (me/100 g)					
0-10	0.18	0.14	0.04	0.20	0.18	0.04
10-20	0.14	0.14	0.02	0.18	0.15	0.04
$LSD_{0.1}$	0.06	0.09	0.02	0.06	0.09	0.02

Table 23

EUF-Extracted Cations from the Tropeptic Eutrustox

Waialua Site

P Applied, kg/ha					
0			196		
Fractions Extracted			Fractions Extracted		
EUF_I	EUF_{II}	EUF_{III}	EUF_I	EUF_{II}	EUF_{III}
Ca (me/100 g)					
0.15[a]	0.36[a]	0.14[a]	0.17[a]	0.42[a]	0.14[a]
Mg (me/100 g)					
0.09[b]	0.23[b]	0.05[b]	0.08[b]	0.18[b]	0.04[b]
K (me/100 g)					
0.09[c]	0.17[c]	0.08[c]	0.09[c]	0.11[c]	0.08[c]
Na (me/100 g)					
0.10[d]	0.04[d]	0.01[d]	0.10[d]	0.04[d]	0.01[d]

Averages for the same nutrient and the same fraction followed by the same letter are not significantly different from each other. ($P < 0.10$)

Table 24

Correlation and Regression Coefficients for the Extractable Cations Found by NH_4OAc and NH_4Cl Methods in the Hydric Dystrandept and the Tropeptic Eutrustox

Extractant/ Cations	n	b_0† (me/100 g)	b_1‡	r
NH OAc - Ca	16	-2.37	1.27	0.984**
NH OAc - Mg	16	0.21	0.88	0.994**
NH OAc - K	16	-0.72	2.17	0.966**
NH OAc - Na	16	0.09	0.769	0.463ns

For the equation $X_2 = b_0 + b_1X_1$, X_2 = NH_4OAc - extractable M^{n+}(me/100 g); X_1 = NH_4Cl - extractable M^{n+}(me/100 g).

† b_0 = intercept

‡ b_1 = slope regression coefficient

** = highly significant ($P < 0.01$)

ns = not significant

The relationships between NH_4OAc and NH_4Cl extractable bases and their EUF counterparts are shown in Table 25. It will be seen that NH_4OAc extractable bases were somewhat more closely related to EUF Ca, Mg, K, and especially Na than the same cations extracted by NH_4Cl. There were significant negative correlations between NH_4OAc Ca and Mg, NH_4Cl Ca and Mg and their EUF counterparts. The relationships, however, were positive when correlation and regression studies were performed for individual soils, although the observed correlation coefficients were not significant.

Earlier it was suggested that specific adsorption of the acetate anion may have taken place during CEC determination. It is possible, therefore, that the new exchange sites created by acetate adsorption have a higher affinity for Ca and Mg and bind them more strongly as observed by Pratt and Bair (1962). Moreover, according to Uehara and Gillman (1981), conventional extraction with NH_4OAc does not give complete removal of divalent cations which, they presume, are held in the Stern layer in some variable-charge soils. Because of the possible incomplete extraction of divalent cations with 1 N NH_4OAc, samples from the top soil of selected treatments were subject to multiple extraction. In each extraction the same amount of NH_4OAc (250 mℓ) was used. The results of such multiple extraction are illustrated in Figures 27, 28, 29, 30, 31 and 32 in Appendix C. It will be seen that a single extraction did not remove all the divalent cations (Ca and Mg). The level of Ca in the

Table 25

Correlation and Regression Coefficients for the Extractable Cations Found by the NH_4OAc, NH_4Cl, and EUF Methods in the Hydric Dystrandept and Tropeptic Eutrustox

Extractant/ Cations	n	b_0† (me/100 g)	b_1‡	r
		NH_4OAc		
EUF - Ca	16	0.83	-0.08	-0.695**
EUF - Mg	16	0.56	-0.09	-0.853**
EUF - K	16	0.18	0.06	0.624**
EUF - Na	16	-0.05	1.05	0.577*
		NH_4Cl		
EUF - Ca	16	0.95	-0.09	-0.594*
EUF - Mg	16	0.54	-0.08	-0.854**
EUF - K	16	0.13	0.13	0.602*
EUF - Na	16	0.34	-0.54	-0.180ns

Models: $X_3 = b_0 + b_1X_1$; $X_3 = b_0 + b_1X_2$

where X_3 = EUF - extractable M^{n+}

X_2 = NH_4Cl - extractable M^{n+}

X_1 = NH_4OAc - extractable M^{n+}

† b_0 = intercept

‡ b_1 = slope regression coefficient

* = significant ($P < 0.05$)

** = highly significant ($P < 0.01$)

ns = not significant

first extraction was about 70 and 86% of the total extracted from the Hydric Dystrandept at the Kukaiau and Philippines sites, respectively, whereas from the Tropeptic Eutrustox at the Waipio site it was about 90% of the total amount extracted. In the second extraction the amount of Ca removed was 15 and 6% for the Kukaiau and the Philippines sites, respectively, and about 6% for the Tropeptic Eutrustox at the Waipio site.

For Mg, the amount extracted in the first extraction from the Hydric Dystrandepts of both the Kukaiau and the Philippines sites was about 88%, whereas it averaged about 95% for the Tropeptic Eutrustox at the Waipio site. The question arises, however, as to whether a divalent cation adsorbed in the Stern layer is exchangeable and whether it is available to plants. Further work is required on this point.

F. Relative Change in Exchangeable Bases with Cropping as Measured by the NH_4OAc and NH_4Cl Methods

Tables 34-45 in Appendix D show the effect of phosphate application on the initial and post-harvest levels of exchangeable Ca, Mg, and K as determined by the NH_4OAc and NH_4Cl methods for the Hydric Dystrandept and the Tropeptic Eutrustox. In order to determine the sensitivity of the NH_4OAc and NH_4Cl methods to variation in exchangeable bases due to P application the data from Tables 34-45 were transformed as follows: The difference between the post-harvest and initial levels of M (M = exchangeable Ca, Mg, or K) was

calculated and referred to as ΔM. For each treatment the algebraic sum of ΔM across the three depths was computed and plotted against the rates of applied phosphate.

1. Hydric Dystrandept. The relationship between the change in exchangeable cationic nutrients and P application is depicted in Figure 20. There was an increase in ΣΔM with increasing rates of applied P. A negative ΣΔM indicates a depletion of the 0-30 cm layer of cationic nutrients, whereas a positive ΣΔM would suggest an accumulation of Ca, Mg, and K. The more negative the ΣΔM, the greater the depletion of cationic nutrients in the 0-30 cm layer due to leaching and crop uptake. As will be shown later, nutrient uptake increased with increasing rates of applied phosphate. One would, therefore, expect ΣΔM to be more negative in plots with high P application if the magnitude of leaching losses from these plots and those which received lower rates of phosphate was similar. The observed increase in ΣΔM with P application, therefore, suggests that leaching losses substantially exceeded nutrient uptake and were likely higher in the low P treatment than in the higher one. Differences between NH_4OAc and NH_4Cl were observed. At low rates of applied P, changes in exchangeable Ca and Mg were higher with NH_4Cl than with NH_4OAc, whereas with exchangeable K, the reverse was true. This suggests that at low rates of applied P the NH_4Cl method gives a higher estimate of leaching losses of divalent cations than does the NH_4OAc method, whereas for K the reverse is true. Recalling that NH_4Cl extracted more

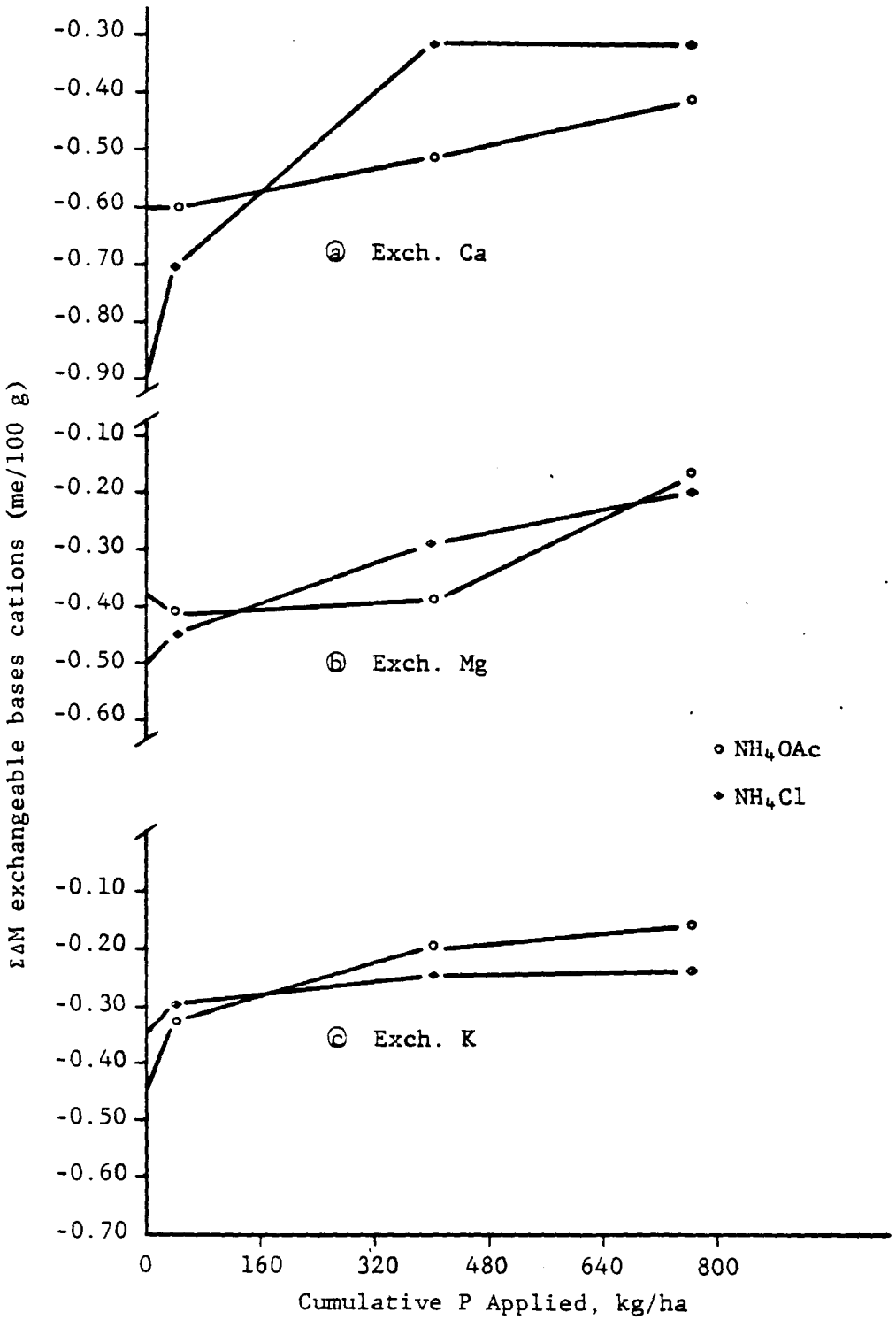


Fig. 20. Variation in the level of exchangeable cations in a Hydric Dystrandept due to P application (Kukaiau site)

divalent cations than NH_4OAc and that the reverse was true for K, it can be inferred from these results that under the experimental conditions of this study the higher the level of cationic nutrients extracted by a given method, the higher the estimate of leaching losses.

2. Tropeptic Eutrustox. Differences in $\Sigma\Delta M$ for Ca and Mg between the low and high P treatments were very small (Figure 21) and as will be shown later, differences in nutrient uptake between these treatments were also very small. This suggests that leaching losses of Ca and Mg from the low and high P treatments were of similar magnitude. These results are consistent with the lack of significant increase in CEC as well as ECEC reported earlier as a result of P applications. Only slight differences in extractable Ca and Mg were found between the NH_4OAc and NH_4Cl methods. With K, however, greater changes were observed with NH_4OAc even in the highest P treatment. It should be pointed out that for the Hydric Dystrandept as well as the Tropeptic Eutrustox the observed decreases in $\Sigma\Delta M$ with increasing rates of applied P were very small (0.1-0.4 me/100 g). On the other hand, since only the 0-30 cm layer was taken into consideration, the values of $\Sigma\Delta M$ may not constitute serious losses given the possibility of Ca, Mg, and K accumulation in the underlying layers.

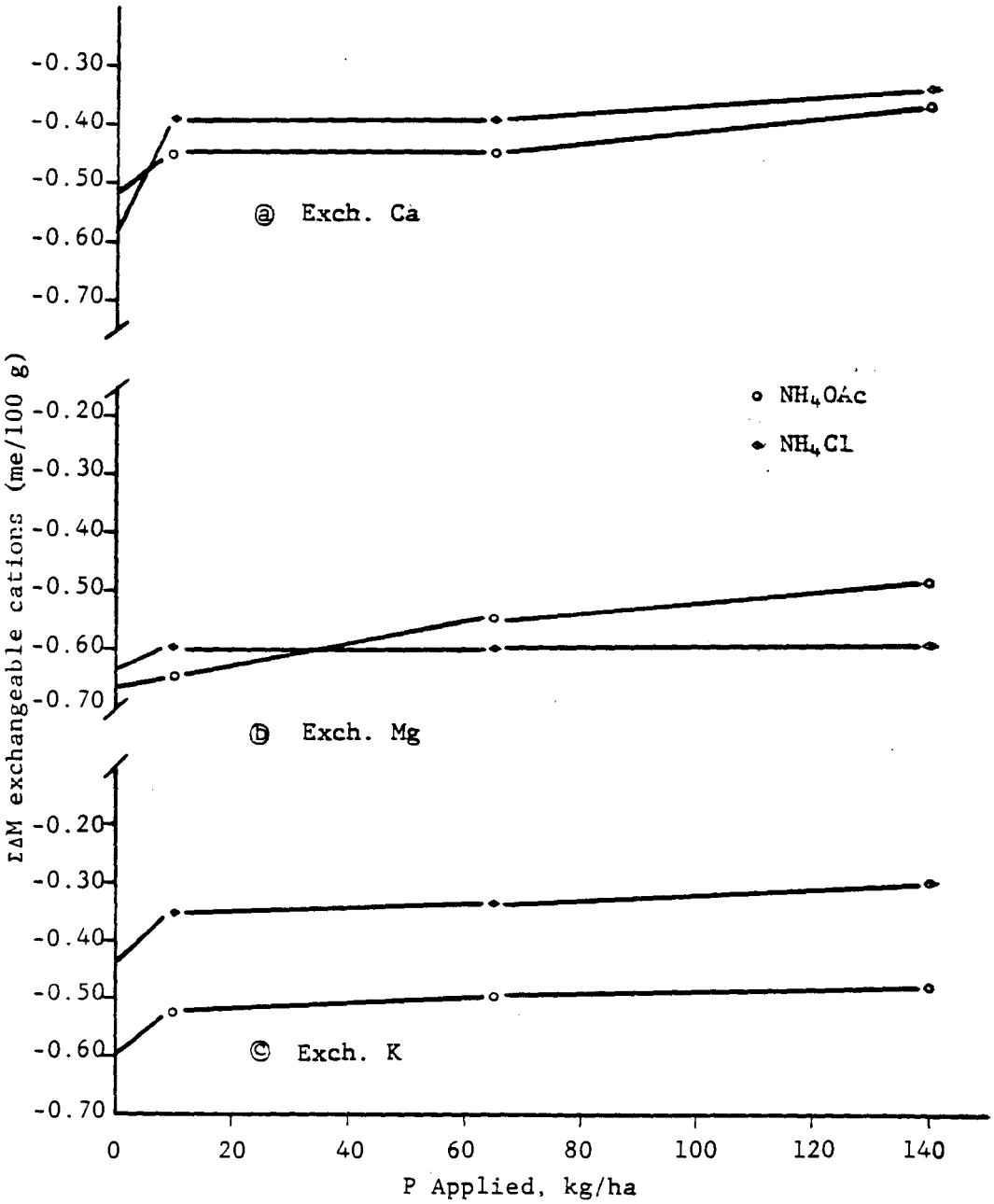


Fig. 21. Variation ir the level of exchangeable cations in a Tropeptic Eutrustox due to P application (Waipio site)

G. Residual Effects of P on Maize Grain Yield and on the Distribution of Nutrients in the Maize Plant

Figure 22 shows the effect of residual phosphate on maize grain yield at Kukaiau and Waipio. At both sites the first P increment was the most effective in increasing maize grain yield. Further P increments did not result in statistically significant increases in yield. The lack of significant response to high rates of applied P at Waipio may be attributed to the effect of lodging caused by the wind as the lodging percentage increased with increasing rates of phosphate. It will be seen from Figure 22 that at high P application maize yield was lower at Waipio than at Kukaiau. This is contrary to what is expected given the higher nutrient status of the Tropeptic Eutrustox and the relatively warmer climatic conditions of Waipio compared with Kukaiau. This is most likely due to the wind damage that occurred three weeks prior to harvest.

The residual effect of rates of phosphate on the distribution of nutrients in maize is shown in Tables 26 and 27 for the Kukaiau and the Waipio sites, respectively. It can be gathered from Tables 26 and 27 that the levels of N, P, and K in grain increased with increasing rates of phosphate. Rates of P, however, had no effect on the level of Ca. As expected, the concentration of K was much higher in stalks and stover than in grain. An interesting feature is that the level of nutrients in grain was much higher in the Waipio site than in the Kukaiau site. This can be looked

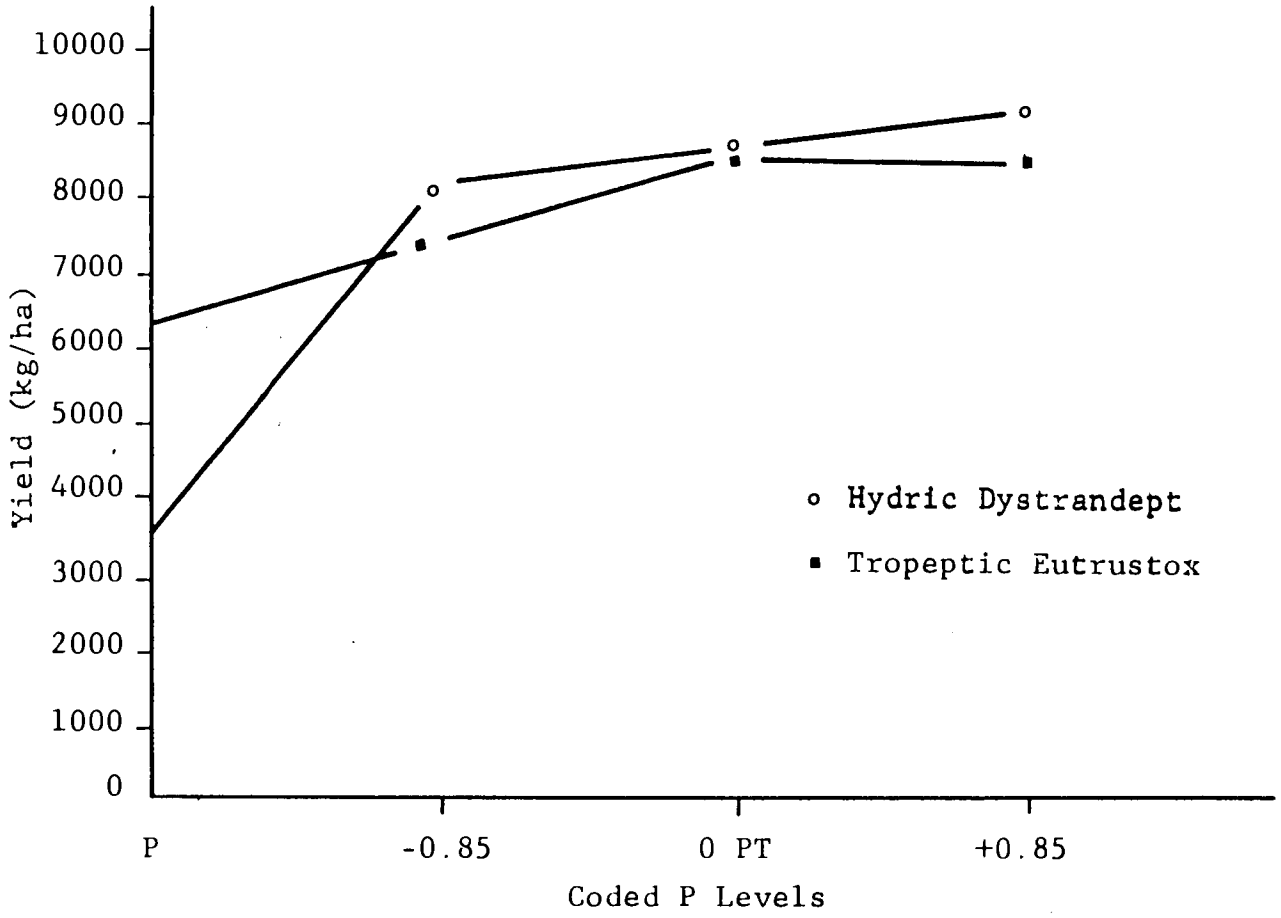


Fig. 22. Residual effect of P on maize grain yield

Table 26

Effect of P Fertilization on the Levels and Distribution of Nutrients in Maize
Kukaiau Site

P Applied kg/ha	Grain					Stover					Cob				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg	N	P	K	Ca	Mg
	per cent					per cent					per cent				
0	1.18	0.26	0.21	0.05	0.09	0.32	0.09	1.10	0.15	0.15	0.40	0.09	0.63	0.07	0.01
40	1.46	0.35	0.32	0.05	0.14	0.32	0.08	1.52	0.13	0.11	0.52	0.09	0.69	0.07	0.01
396	1.39	0.33	0.24	0.05	0.13	0.28	0.09	1.64	0.13	0.10	0.49	0.09	0.53	0.07	0.01
750	1.45	0.37	0.32	0.05	0.15	0.31	0.08	1.56	0.14	0.10	0.50	0.09	0.49	0.07	0.01

Table 27

Effect of P Fertilization on the Levels and Distribution of Nutrients in Maize
Waipio Site

P Applied kg/ha	Grain					Stalk				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
	per cent					per cent				
0	1.53	0.50	0.37	0.05	0.18	0.35	0.09	2.69	0.15	0.23
10	1.66	0.56	0.39	0.05	0.21	0.38	0.08	2.46	0.16	0.26
65	1.75	0.76	0.50	0.05	0.26	0.45	0.09	2.69	0.15	0.24
140	1.67	0.62	0.42	0.05	0.22	0.50	0.10	2.67	0.16	0.23

	Leaves					Cob				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
	per cent					per cent				
0	0.86	0.16	0.40	0.45	0.52	0.40	0.09	0.41	0.07	0.02
10	0.99	0.13	0.48	0.42	0.51	0.37	0.08	0.36	0.07	0.01
65	1.06	0.14	0.46	0.44	0.48	0.32	0.08	0.36	0.07	0.01
140	1.02	0.15	0.50	0.44	0.51	0.43	0.10	0.39	0.08	0.03

upon as a direct consequence of the higher nutrient status of the Tropeptic Eutrustox than the Hydric Dystrandept. Total nutrient uptake is shown in Tables 28 and 29 for Kukaiau and Waipio, respectively. At Kukaiau there was a gradual increase in total nutrient uptake with increasing phosphorus rates. At Waipio, however, no definite trend was observed, presumably because of the lodging.

By way of contrast total nutrient uptake was higher at Waipio than at Kukaiau. This can be explained by the higher nutrient concentrations found in maize grown at Waipio.

Correlation and regression coefficients were calculated for the linear regression of total nutrient uptake with the same nutrients extracted from soil samples taken before planting by the NH_4OAc, NH_4Cl, and EUF methods (Tables 48, 49 and 50 in Appendix G). Data from the Hydric Dystrandept and the Tropeptic Eutrustox were combined in the regression analysis. Higher correlation coefficients for Ca (0.92 and 0.89 vs 0.70 to 0.86) and Mg (0.95 and 0.96 vs 0.20 to 0.79) were obtained with NH_4OAc and N_4Cl than with EUF, suggesting that NH_4OAc and NH_4Cl - Ca and Mg represent the fractions of Ca and Mg taken up by maize. The negative correlation coefficients obtained for Ca and Mg with EUF are due to the fact that the quantities of these cations found by EUF in the Hydric Dystrandept were higher than those found in the Tropeptic Eutrustox, whereas the reverse was true for total Ca and Mg uptake.

Table 28

Total Nutrient Uptake by Maize Grown on a Hydric Dystrandept from Hawaii Kukaiau Site

P Applied kg/ha	Ca	Mg	K	Na
	kg/ha			
0	7.76	8.05	48.83	2.36
40	13.72	18.40	128.70	4.58
396	14.51	17.98	133.46	5.64
750	14.76	19.96	139.27	5.28

Table 29

Total Nutrient Uptake by Maize Grown on a Tropeptic Eutrustox from Hawaii Waipio Site

P Applied kg/ha	Ca	Mg	K	Na
	kg/ha			
0	30.71	47.77	239.10	13.05
10	25.66	44.95	196.39	12.36
65	28.42	52.05	238.31	13.90
140	29.95	50.13	231.08	11.90

For K, significant correlation coefficients were obtained with NH_4OAc (0.84) and EUF_{III} (0.90). When correlation and regression studies were performed for individual soils, generally higher correlation coefficients were obtained for K and Na with EUF than with NH_4OAc and NH_4Cl. These results suggest that for K, only the NH_4OAc - K and EUF_{III} - K represent the fraction of soil K taken up by maize. Significant correlation coefficients for P uptake were obtained only with the different fractions extracted by the EUF method (Table 50). The EUF_I and EUF_{II} fractions, which constitute the readily available P, appeared to be more closely related to P uptake than EUF_{III} which represents the soil P reserve.

H. Balance Sheet Approach

In an effort to evaluate the fate of applied cationic nutrients and the behavior of native exchangeable cations, a balance sheet of Ca, Mg, and K was constructed. The establishment of this balance sheet, however, involves certain assumptions of accurate sampling of both plant and soil material. Moreover, only exchangeable cations were taken into account. For these reasons the established balance sheet should be considered approximate.

1. Hydric Dystrandept. The relationship between cationic nutrients unaccounted for and the rates of applied P is depicted in Figures 23 and 24. The amount of nutrient unaccounted for is defined as

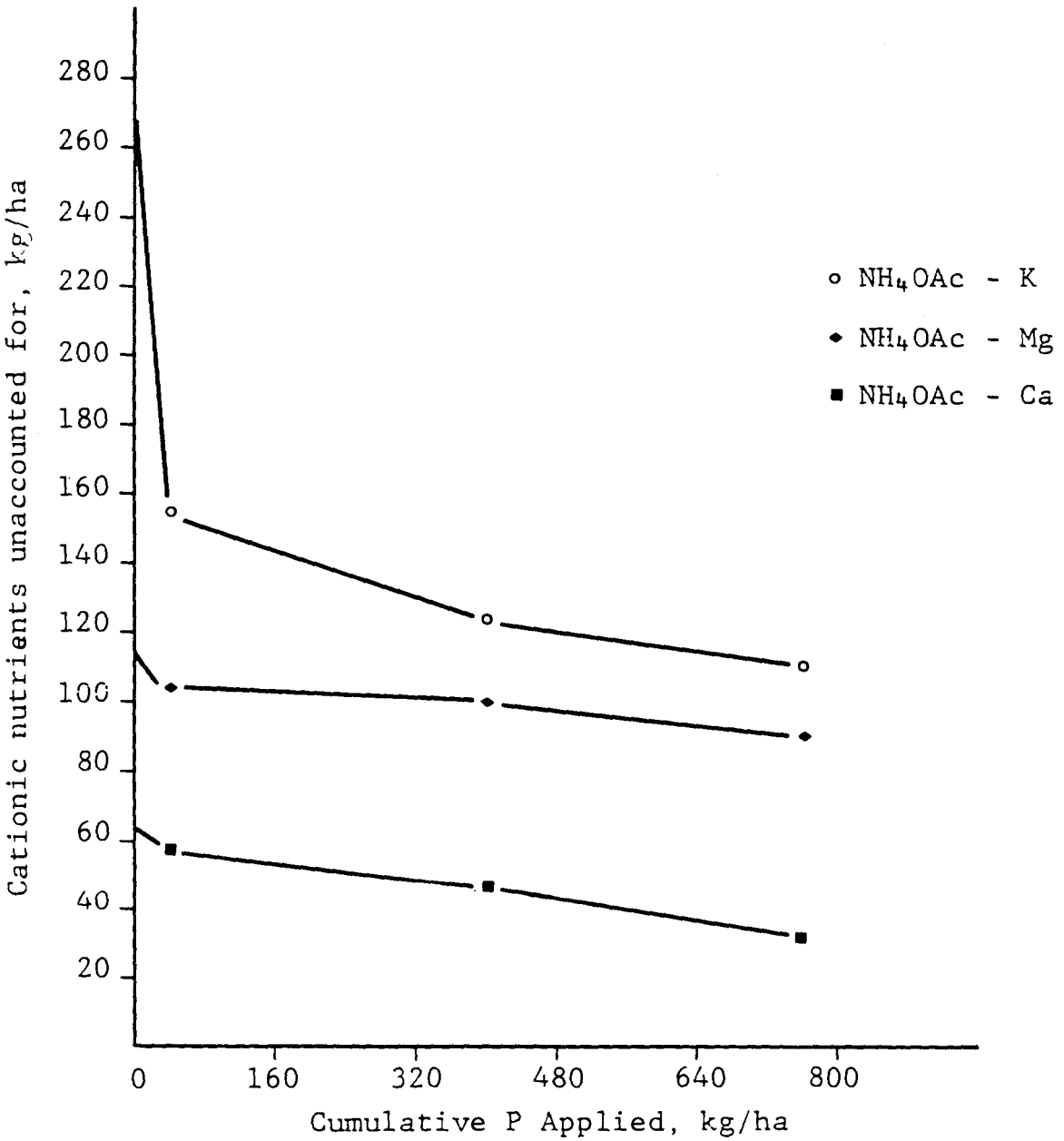


Fig. 23. Relationship between Ca, Mg, and K unaccounted for and the rates of P applied (Kukaiau site)

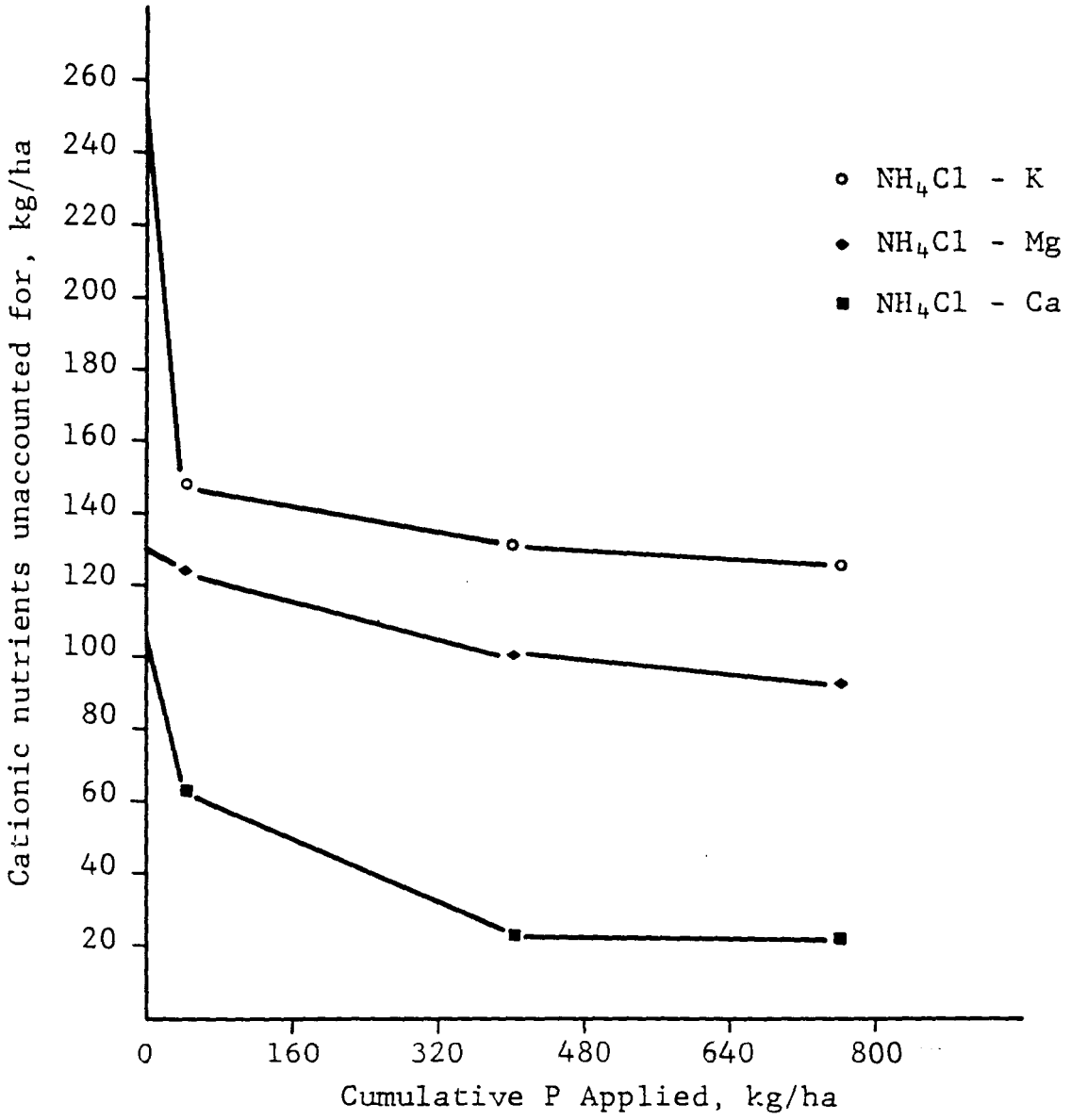


Fig. 24. Relationship between Ca, Mg, and K unaccounted for and the rates of P applied (Kukaiau site)

$$M_{\text{unaccounted for}} = M_a + M_i - M_r - M_u$$

where M = any given cation; a, i, r, and u refer to the cation applied, measured initially, remaining after the crop, and taken up, respectively. The values of the bulk density for the 0-10, 10-20, and 20-30 cm layers were taken as 0.68, 0.57, and 0.53 g/cm^3, respectively (Soil Survey Investigations, 1976).

There was a gradual decrease in the amount of Ca, Mg, and K unaccounted for with increasing rates of applied P. The trend was similar for NH_4OAc and NH_4Cl extractable bases. One possible explanation is that with increased crop production as a result of higher P application a greater amount of cationic nutrients is taken up from the applied, as well as the native, exchangeable cations. The amount of Ca and Mg unaccounted for was higher with NH_4Cl in the low P treatments, whereas for K, NH_4OAc gave higher values. An interesting feature is that the level of cationic nutrients unaccounted for decreased in the order K > Mg > Ca, suggesting greater potassium losses, presumably by leaching. The following amounts of Ca, Mg, and K unaccounted for, expressed as percentages of the initial plus the applied quantity of each cation, were found in the low P treatment: Ca: 10%, Mg, 22%, K: 35%.

2. Tropeptic Eutrustox. The values of the bulk density for the 0-10, 10-20 and 20-30 cm layers were taken as 0.97, 1.05, and 1.14 g/cm^3, respectively (Soil Survey Investigations, 1976).

The general trends noted for the Hydric Dystrandept were observed for the Tropeptic Eutrustox (Figures 25 and 26), viz., the amount of Ca, Mg, and K unaccounted for decreased with increasing rates of applied phosphate. At low rates of phosphate, NH_4Cl gave higher values of Ca, Mg, and K unaccounted for. Again the level of K unaccounted for is much higher than that of Ca and Mg.

The following amounts of Ca, Mg, and K unaccounted for, expressed as percentages of the initial plus the applied quantity of each cation, were found in the low P treatment: Ca: 2%, Mg: 6%, K: 9%.

By way of contrast, the amounts of Ca, Mg, and K unaccounted for were generally higher at the Kukaiau site than at the Waipio site. This, however, can be due to the higher nutrient uptake observed at Waipio compared to Kukaiau as well as the possible greater leaching losses of exchangeable cations at Kukaiau as a result of higher rainfall.

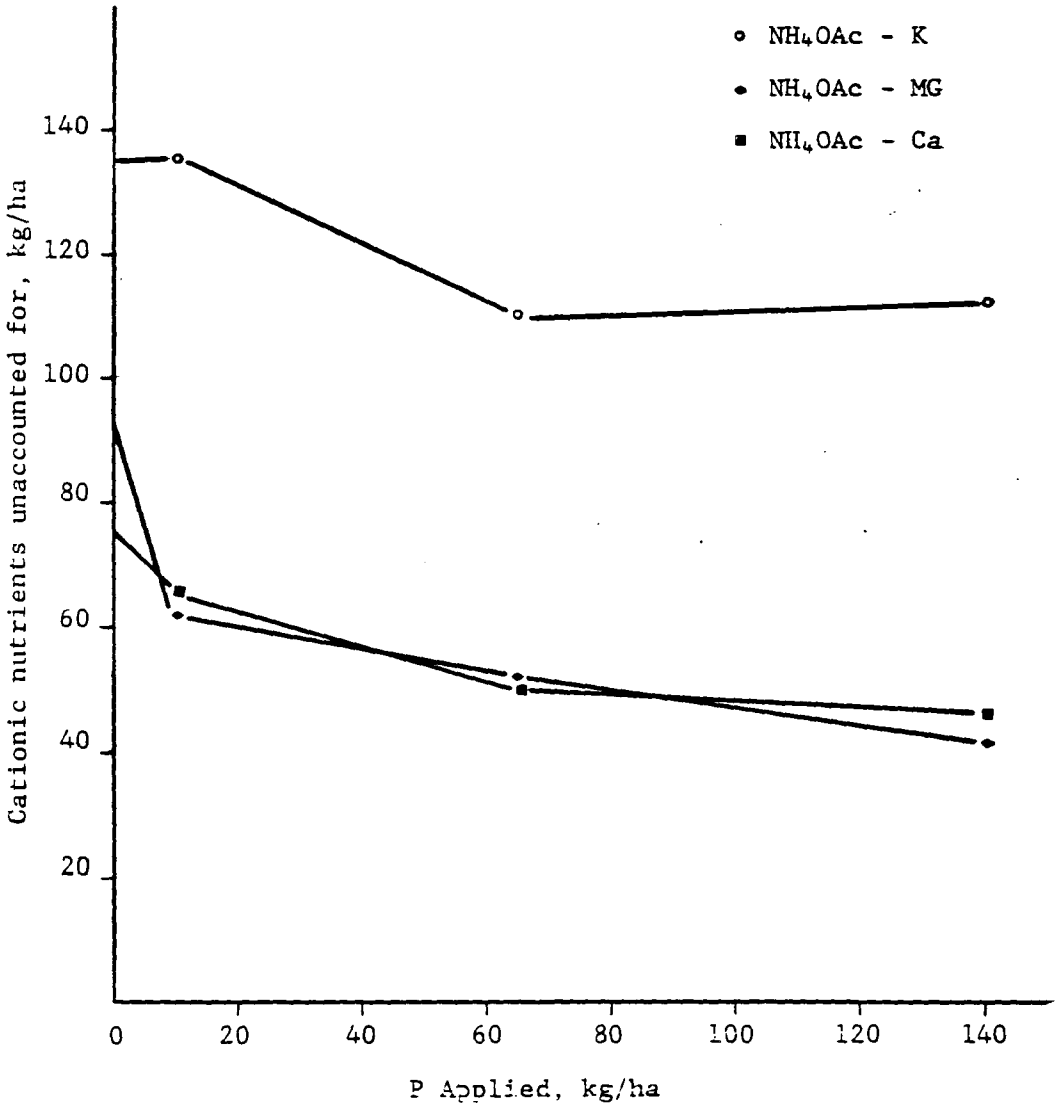


Fig. 25. Relationship between Ca, Mg, and K unnaccounted for and the rates of P applied (Waipio site)

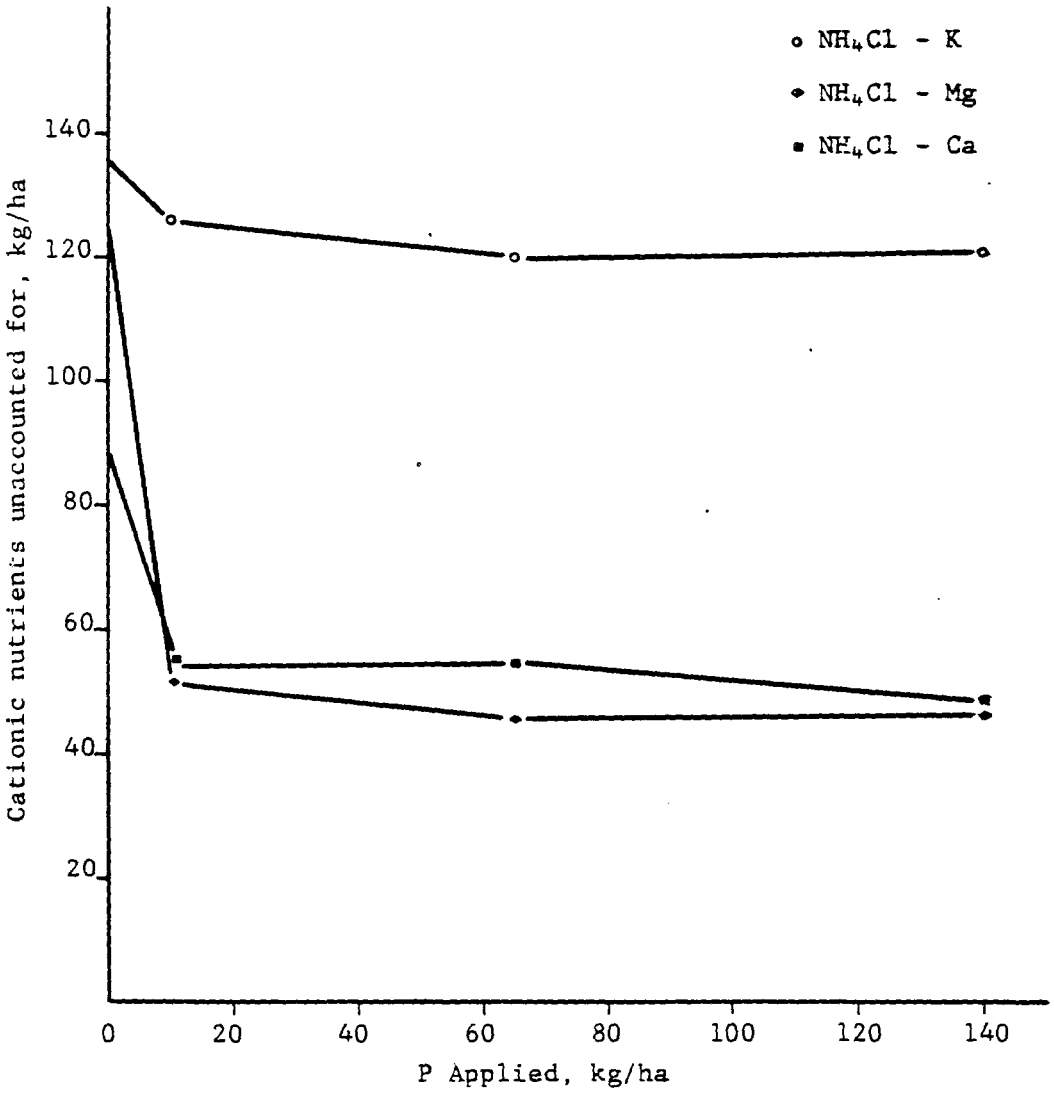


Fig. 26. Relationship between Ca, Mg, and K unaccounted for and the rates of P applied (Waipio site)

V. CONCLUSIONS

The effect of long-term phosphate fertilization on CEC and the movement of cations in the soil profile of variable-charge soils was investigated. Phosphorous application of 750 kg P/ha to a Hydric Dystrandept was found to increase NH_4OAc - CEC and ECEC by 4.13 and 1.82 mg/100 g, respectively. The increase in NH_4OAc - CEC and ECEC is equivalent to an increase of 0.37 and 0.16 me/100 g per 100 ppm of applied P, respectively. However, phosphate had no significant effect on the CEC of Tropeptic Eutrustox. Cationic nutrients became less susceptible to leaching into the lower depths in the soil profile as a result of increased CEC. These results indicate that CEC of some variable-charge soils in the tropics can be increased by field application of high rates of phosphate.

NH_4Cl gave higher values of extractable divalent cations, whereas for K, higher values were obtained with NH_4OAc. The conventional extraction with 1 N NH_4OAc did not give complete removal of divalent cations (Ca, Mg) when compared to the total cations removed by multiple extraction with NH_4OAc. The quantities of Ca and Mg extracted in the first extraction were 70 to 90% and 88 to 95% of the total amount of each cation extracted, respectively.

The results further showed that the levels of EUF extractable bases were much lower than those of NH_4OAc and NH_4Cl extractable bases. EUF Ca and Mg values were higher in the Hydric Dystrandept than in the Tropeptic Eutrustox; however, the reverse was true for EUF K and Na values.

At the Waipio, as well as the Kukaiau sites, the first P increment was the most effective in increasing maize grain yield. Additional P increments did not result in statistically significant increases in yield. The concentration of N, P, K, and Mg in maize grain increased with increasing rates of applied phosphorus. P application, however, had no effect on the concentration of Ca in maize grain.

The level of cationic nutrients unaccounted for decreased in the order K > Mg > Ca, suggesting greater potassium losses, presumably by leaching.

Correlation studies between initial levels of nutrients in the soils determined with the three extractants and total nutrient uptake suggest that NH_4OAc - K and EUF_{III} - K represent the form of K taken up by maize. The Ca and Mg extracted by NH_4OAc and NH_4Cl were more closely correlated with Ca and Mg uptake than EUF extracted Ca and Mg. EUF - P appeared more closely related to P uptake than P found by the modified Truog method.

APPENDIX A

SOIL PROFILE DESCRIPTIONS

Profile description of a Hydric Dystrandept from Hawaii (Kukaiau) after Ikawa (1979)

Ap 1 0-17 cm; dark brown (7.5 YR 3/2) and very dark brown (10 YR 2/2) silt loam; moderate fine and medium platy structure breaking to very fine and fine granular structure; friable, slightly sticky, slightly plastic, weakly smeary; many roots; occasional red cinders, approximately 2 cm in diameter; abrupt smooth boundary

Ap 2 17-23 cm; dark brown (7.5 YR 3/2) and very dark brown (10 YR 2/2) silt loam; moderate very fine and fine subangular blocky structure breaking to fine and very fine granular structure; friable, sticky, plastic, weakly smeary; many roots; abrupt smooth boundary

B 21 23-42 cm; dark reddish brown (5 YR 3/2) silt loam; weak very fine and fine subangular blocky structure; friable, sticky, plastic, weakly smeary; many roots; clear smooth boundary

B 22 42-60 cm; dark reddish brown (5 YR 3/2, 3/3) silt loam; weak very fine and fine subangular blocky structure; friable, sticky, plastic, weakly smeary; many roots; clear smooth boundary

B 23 60-100 cm; dark brown (7.5 YR 4/4) silt loam; moderate very fine and fine subangular blocky structure; friable, sticky, plastic, moderately smeary; many roots; clear smooth boundary

B 24 100-130 cm; dark reddish brown (5 YR 3/4) silty clay loam; moderate very fine and fine subangular blocky structure; friable, sticky, plastic, moderately smeary; many roots; abrupt irregular boundary

B 25 120-160 cm; dark reddish brown (5 YR 3/3) silty clay loam; moderate very fine and fine subangular blocky structure; friable, sticky, plastic, moderately smeary; many roots

II R Weathering pahoehoe lava

Profile description of a Tropeptic Eutrustox from Hawaii (Waipio) after Ikawa (1979)

Ap 1 0-10 cm; dark reddish brown (2.5 YR 2.5/4) silty clay; strong very fine and medium subangular structure; strong very fine and fine granular structure on surface; extremely hard, firm, sticky, plastic; many very fine and fine roots, few medium roots; many very fine and fine pores; many black concretions, less than 1 to 1 mm in diameter, slightly larger (approximately 2 mm) concretions are on surface; gradual smooth boundary

Ap 2 10-27 cm; dark reddish brown (2.5 YR 2.5/4) silty clay; moderate very fine and medium subangular blocky structure; friable, sticky, plastic; many very fine and fine roots, few medium roots; many very fine and fine pores; many black concretions, less than 1 mm in diameter; clean smooth boundary

AB 27-40 cm; dark reddish brown (2.5 YR 2.5/4) silty clay; moderate fine and medium subangular blocky structure; firm, sticky, plastic; many very fine and fine roots; many very fine and fine pores; many black concretions, less than 1 mm in diameter; abrupt smooth boundary

B 21 40-65 cm; dusky red (10 R 3/3) and dark reddish brown (2.5 YR 2.5/4) silty clay; moderate fine and medium subangular blocky structure; hard, friable, slightly sticky, plastic; common very fine roots; many very fine and fine pores; many black concretions, less than 1 mm in diameter; few thin clay film-like materials on peds and in pores; clear smooth boundary

B 22 65-90 cm; dusky red (10 R 3/3) and dark reddish brown (2.5 YR 2.5/4) silty clay; strong very fine, fine, and medium subangular blocky structure; extremely hard, friable, sticky, plastic; few very fine roots, many very fine and fine pores; common black concretions, less than 1 mm in diameter; common thin clay film-like material on peds and in pores; gradual smooth boundary

B 23 90-120 cm; dusky red (10 R 3/3) and dark reddish brown (2.5 YR 2.5/4) silty clay; strong very fine, fine, and medium subangular structure; extremely hard, friable, sticky, plastic; many fine pores; some root pores coated with black material; many thin and moderately thick clay film-like materials on peds and in pores; diffuse boundary

B 24 120-150 cm; dusky red (10 R 3/3) and dark reddish brown (2.5 YR 2.5/4) silty clay; strong very fine and fine subangular blocky structure; extremely hard, friable, sticky, plastic; many fine pores; some root pores coated with black material; many thin and moderately thick clay film-like materials on peds and pores

APPENDIX B

EFFECT OF P FERTILIZATION ON CEC

Table 30

Effect of P Treatments on NH_4OAc - CEC* of a Hydric Dystrandept from Hawaii Kukaiau Site

Depth (cm)	Rates of P Applied, kg/ha			
	0	40	396	750
	me/100 g			
0-10	35.68** n	36.16 mn	38.38 lm	39.81 kl
10-20	41.42 ghk	43.78 fg	40.68 hkl	43.26 fgh
20-30	49.72 ab	50.56 ab	44.44 ef	49.12 bcd
30-45	50.05 a	49.04 bcd	48.90 bcd	46.56 de
45-60	47.08 ab	47.35 cd	41.58 ghk	49.78 bc

* Average of 3 replicates

** Averages followed by the same letter are not significantly different from each other at the 10% level.

Table 31

Effect of P Fertilization on NH_4Cl - CEC* of a Hydric Dystrandept from Hawaii Kukaiau Site

Depth (cm)	Rates of P Applied, kg/ha			
	0	40	396	750
	me/100 g			
0-10	16.60** h	16.90 h	18.02 gh	18.87 gh
10-20	21.47 fgh	23.41 defg	21.64 fgh	22.41 efgh
20-30	27.86 bcde	31.54 abc	25.39 cdef	26.41 cdef
30-45	34.47 a	28.71 abcd	33.94 ab	28.39 abcde
45-60	33.51 ab	33.15 ab	30.16 abc	30.73 abc

* Average of 3 replicates

** Averages followed by the same letter are not significantly different from each other at the 10% level.

Table 32

Effect of P Fertilization on NH_4OAc - CEC* of a Tropeptic Eutrustox from Hawaii Waipio Site

Depth (cm)	Rates of P Applied, kg/ha			
	0	10	65	140
	me/100 g			
0-10	17.28** abc	17.24 abc	16.62 abcd	18.14 ab
10-20	14.87 bcde	14.96 bcde	15.00 bcde	17.73 a
20-30	14.52 bcde	14.88 bcde	14.84 bcde	13.98 cde
30-45	14.79 bcde	15.25 abcde	14.24 cde	14.60 bcde
45-60	12.89 e	11.90 e	12.70 de	12.79 e

* Average of 3 replicates

** Averages followed by the same letter are not significantly different from each other at the 10% level.

Table 33

Effect of P Fertilization on NH_4Cl - CEC* of a Tropeptic Eutrustox from Hawaii Waipio Site

Depth (cm)	Rates of P Applied, kg/ha			
	0	10	65	140
	me/ 100 g			
0-10	13.91** abc	14.18 ab	14.26 ab	14.55 a
10-20	12.74 abcde	13.00 abcd	12.22 bcde	13.35 abcd
20-30	13.03 abc	12.74 abcde	12.81 abcde	12.02 cde
30-45	11.59 de	11.31 de	11.91 cde	11.80 e
45-60	10.88 e	19.82 de	10.35 cde	10.44 e

* Average of 3 replicates

** Averages followed by the same letter are not significantly different from each other at the 10% level.

APPENDIX C

MULTIPLE EXTRACTION OF DIVALENT CATIONS (Ca, Mg)

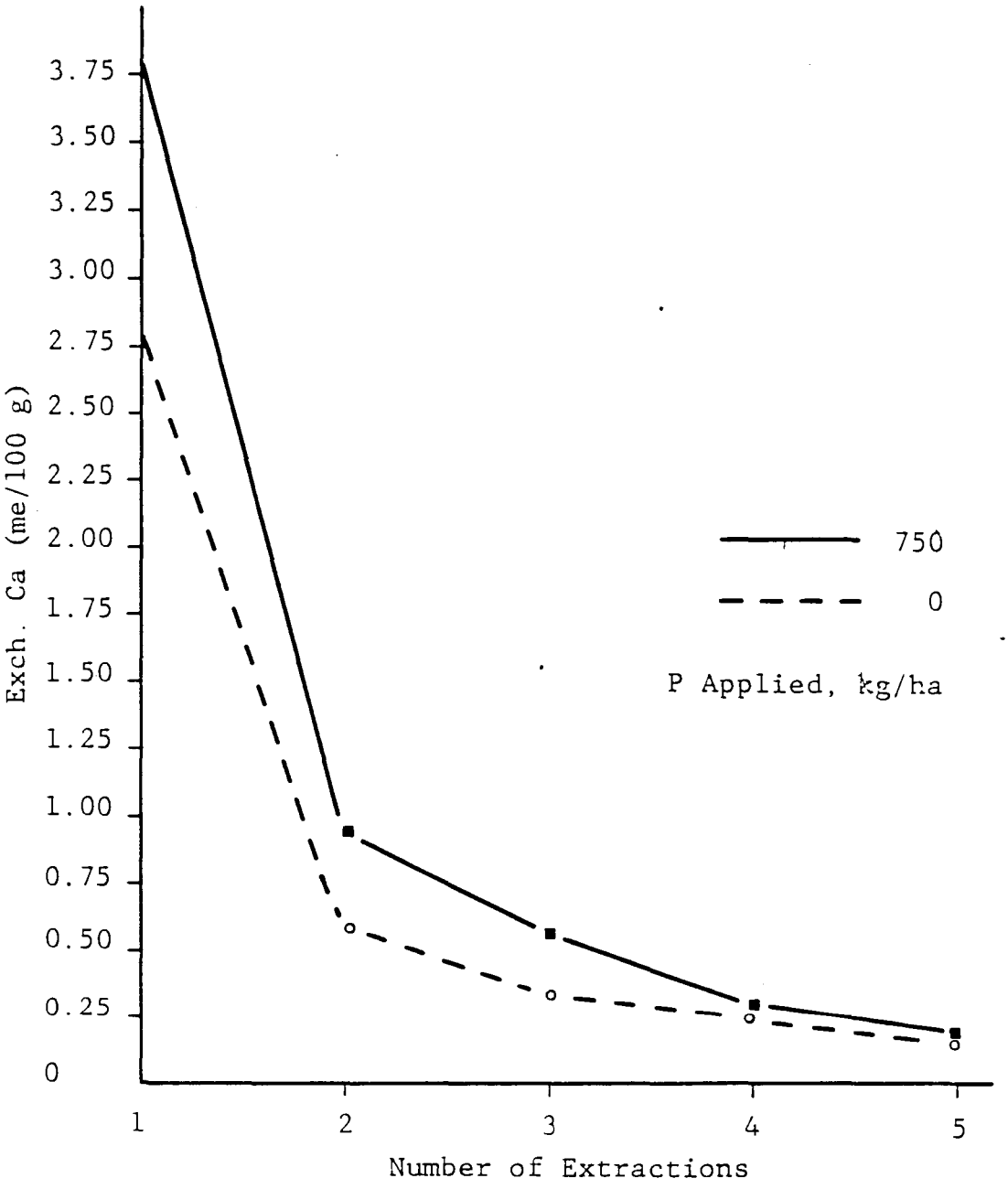


Fig. 27. Multiple extraction of exchangeable Ca by NH_4OAc from a Hydric Dystrandept from Hawaii (Kukaiau Site)

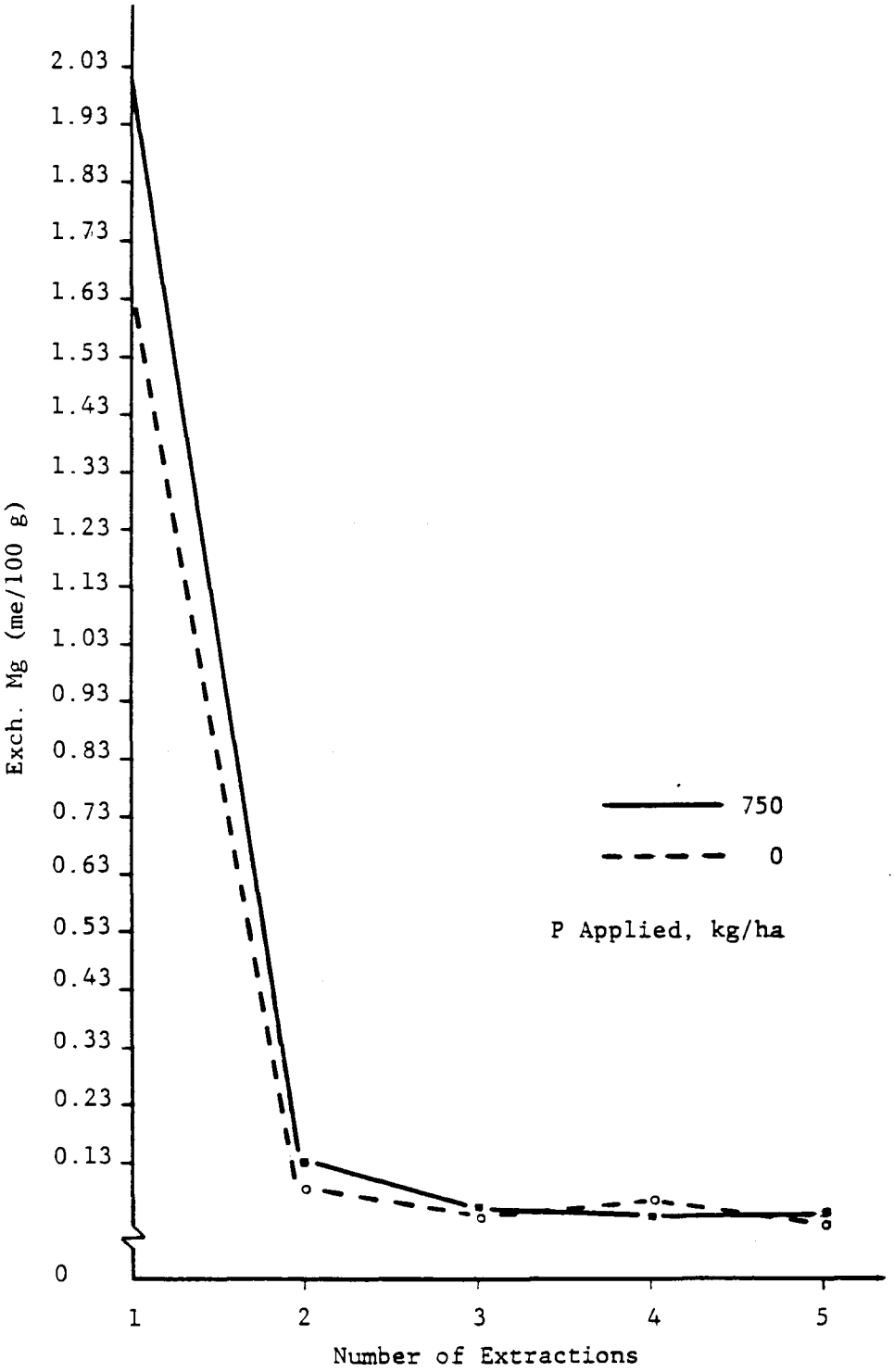


Fig. 28. Multiple extraction of exchangeable Mg by NH_4OAc from a Hydric Dystrandept from Hawaii (Kukaiau Site)

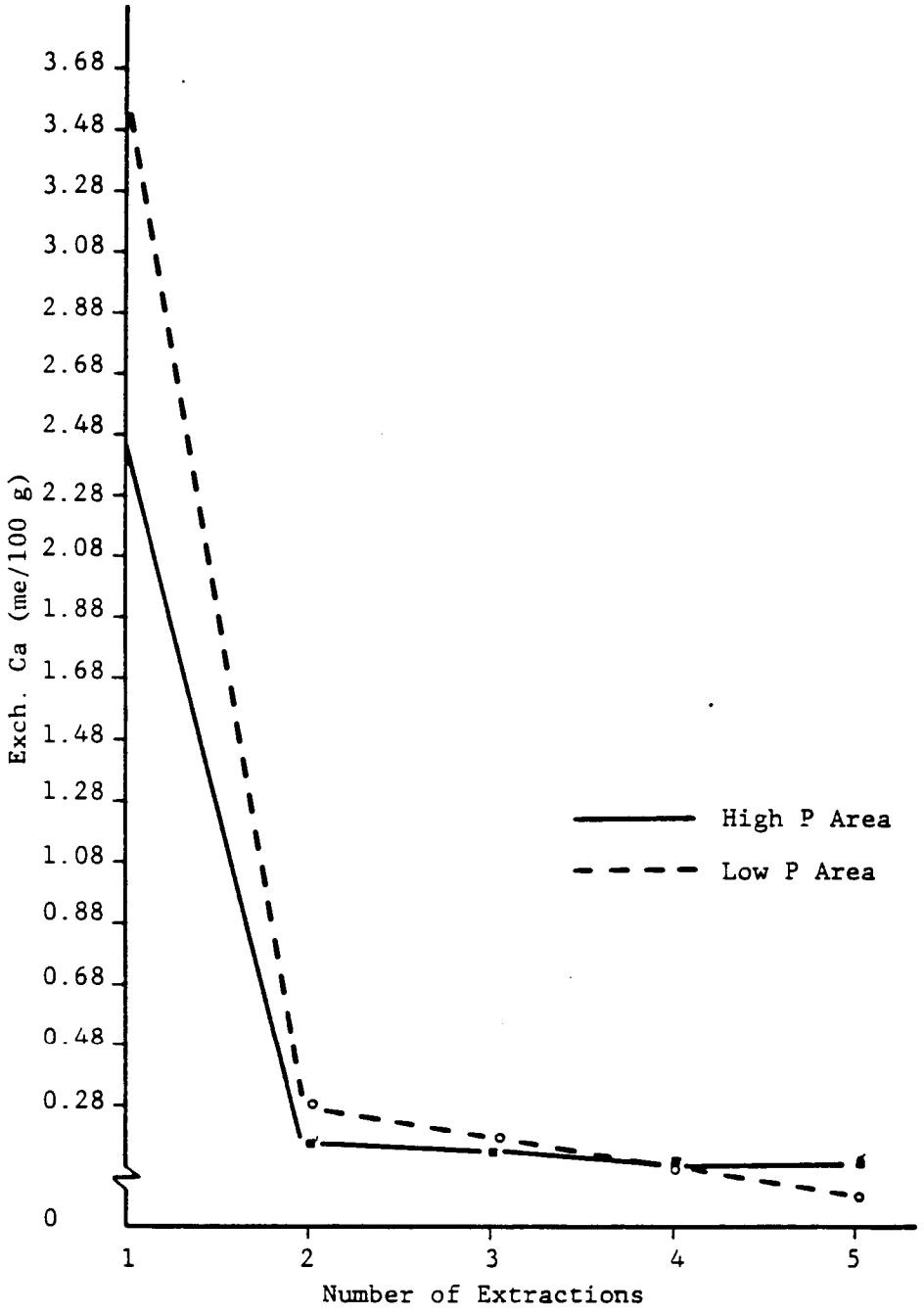


Fig. 29. Multiple extraction of exchangeable Ca by NH_4OAc from a Hydric Dystrandept from the Philippines

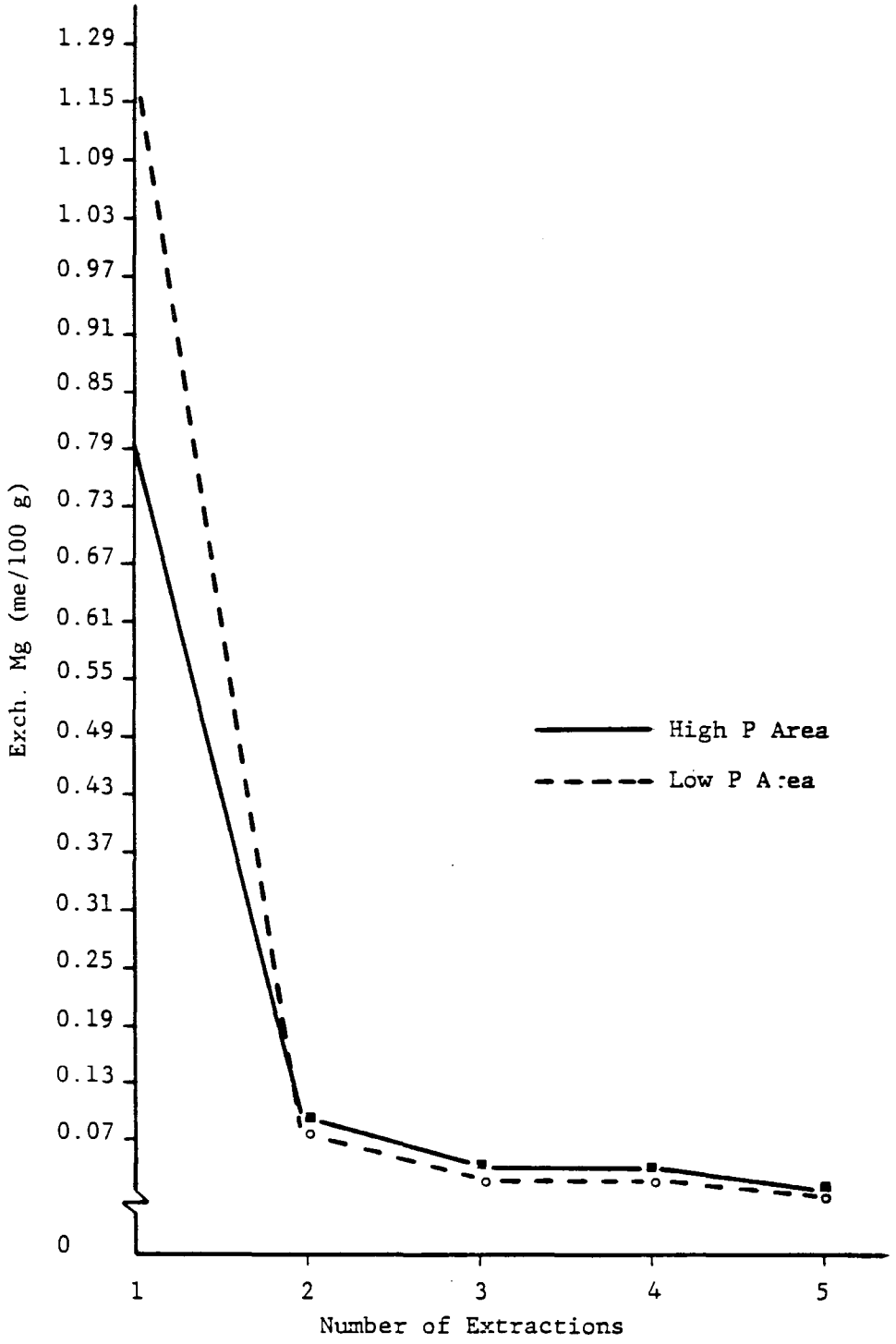


Fig. 30. Multiple extraction of exchangeable Mg by NH_4OAc from a Hydric Dystrandept from the Philippines

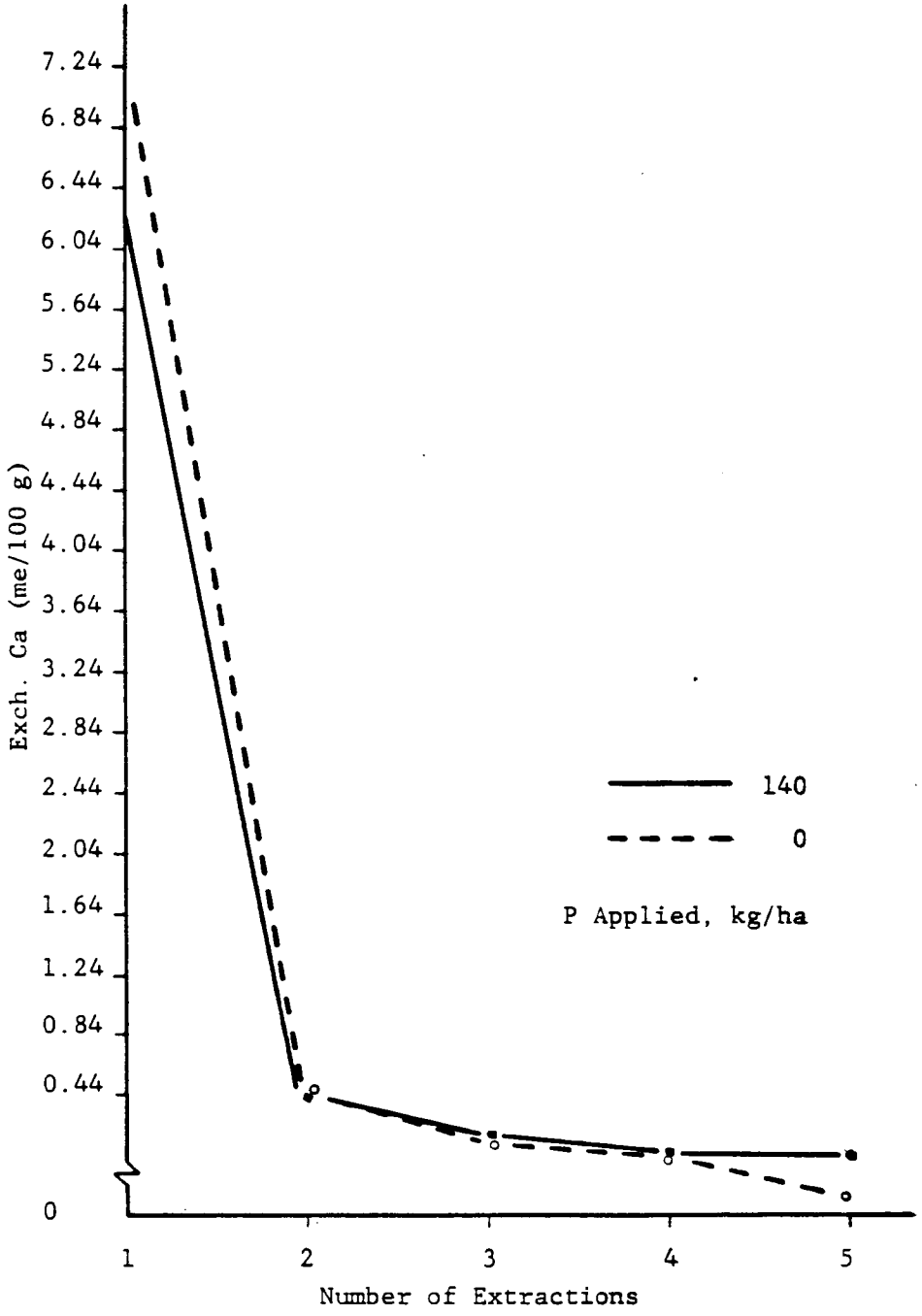


Fig. 31. Multiple extraction of exchangeable Ca by NH_4OAc from a Tropeptic Eutrustox from Hawaii (Waipio Site)

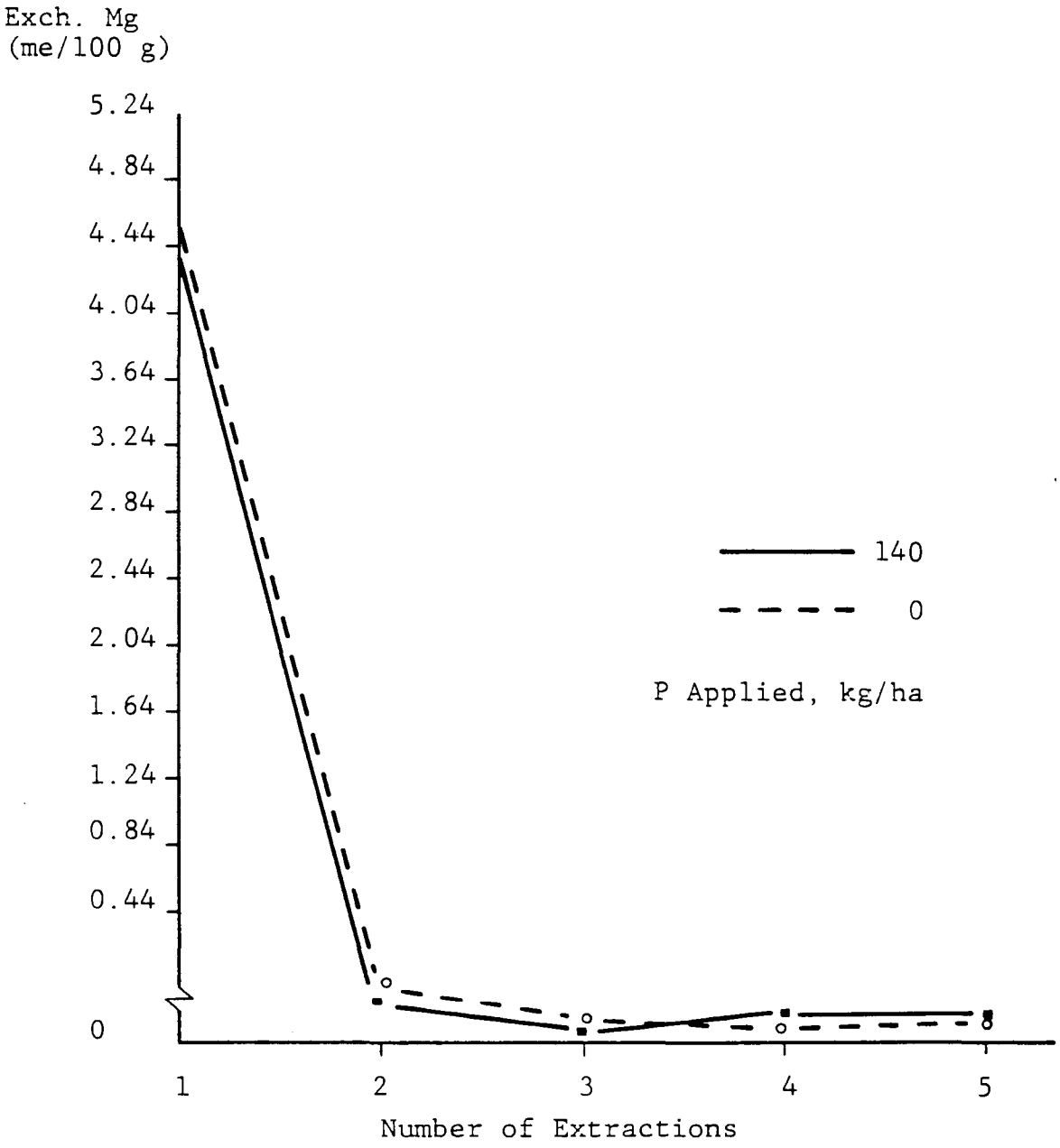


Fig. 32. Multiple extraction of exchangeable Mg by NH_4OAc from a Tropeptic Eutrustox from Hawaii (Waipio Site)

APPENDIX D

EFFECT OF P ON INITIAL AND POSTHARVEST NH_4OAc AND NH_4Cl EXTRACTABLE BASES

Table 34

Effect of P Rates on Initial and Postharvest (P-H) NH_4OAc-Extractable Ca of a Hydric Dystrandept from Hawaii Kukaiau Site

Depth (cm)	P Applied, kg/ha							
	0		40		396		750	
	Initial	P-H	Initial	P-H	Initial	P-H	Initial	P-H
	me/100 g							
0-10	1.69	1.44	1.72	1.50	2.34	1.89	3.18	2.65
10-20	1.52	1.34	1.92	1.67	2.23	2.35	2.34	2.65
20-30	1.84	1.66	2.22	2.07	3.12	2.97	3.32	3.19

Initial $LSD_{0.1} = 0.50$

P-H $LSD_{0.1} = 0.84$

Table 35

Effect of P Rates on Initial and Postharvest (P-H) NH_4OAc-Extractable Mg of a Hydric Dystrandept from Hawaii Kukaiau Site

Depth (cm)	P Applied, kg/ha							
	0		40		396		750	
	Initial	P-H	Initial	P-H	Initial	P-H	Initial	P-H
	me/100 g							
0-10	1.60	1.46	1.79	1.40	1.76	1.38	1.80	1.55
10-20	2.07	2.22	2.00	1.93	1.67	1.49	1.69	1.75
20-30	3.07	2.68	2.62	2.66	2.47	2.64	2.42	2.46

Initial $LSD_{0.1} = 0.38$

P-H $LSD_{0.1} = 0.27$

Table 36

Effect of P Rates on Initial and Postharvest (P-H) NH_4OAc-Extractable K of a Hydric Dystrandept from Hawaii Kukaiau Site

Depth (cm)	P Applied, kg/ha							
	0		40		396		750	
	Initial	P-H	Initial	P-H	Initial	P-H	Initial	P-H
	me/100 g							
0-10	0.85	0.62	0.84	0.65	0.83	0.72	0.91	0.81
10-20	0.78	0.65	0.72	0.62	0.64	0.57	0.62	0.53
20-30	0.73	0.62	0.60	0.54	0.48	0.43	0.46	0.44

Initial $LSD_{0.1} = 0.18$

P-H $LSD_{0.1} = 0.13$

Table 37

Effect of P Rates on Initial and Postharvest (P-H) NH_4Cl-Extractable Ca of a Hydric Dystrandept from Hawaii Kukaiau Site

Depth (cm)	P Applied, kg/ha							
	0		40		396		750	
	Initial	P-H	Initial	P-H	Initial	P-H	Initial	P-H
	me/100 g							
0-10	2.87	2.58	3.56	3.42	4.43	4.13	4.78	4.55
10-20	2.66	2.38	3.38	3.22	4.03	4.27	4.27	4.38
20-30	2.98	2.58	4.97	4.58	4.54	4.31	4.48	4.30

Initial $LSD_{0.1} = 0.56$

P-H $LSD_{0.1} = 0.59$

Table 38

Effect of P Rates on Initial and Postharvest (P-H) NH_4Cl-Extractable Mg of a Hydric Dystrandept from Hawaii
Kukaiau Site

Depth (cm)	P Applied, kg/ha							
	0		40		396		750	
	Initial	P-H	Initial	P-H	Initial	P-H	Initial	P-H
	me/100 g							
0-10	1.69	1.25	1.66	1.14	1.76	1.27	1.81	1.49
10-20	2.01	2.02	1.75	1.60	1.65	1.61	1.66	1.68
20-30	2.53	2.46	2.28	2.48	1.88	2.26	2.07	2.19

Initial $LSD_{0.1} = 0.53$

P-H $LSD_{0.1} = 0.44$

Table 39

Effect of P Rates on Initial and Postharvest (P-H) NH_4Cl-Extractable K of a Hydric Dystrandept from Hawaii Kukaiau Site

Depth (cm)	P Applied, kg/ha							
	0		40		396		750	
	Initial	P-H	Initial	P-H	Initial	P-H	Initial	P-H
	me/100 g							
0-10	0.76	0.60	0.73	0.55	0.65	0.51	0.82	0.70
10-20	0.72	0.56	0.66	0.56	0.54	0.43	0.62	0.51
20-30	0.60	0.54	0.36	0.33	0.34	0.31	0.45	0.40

Initial $LSD_{0.1} = 0.20$

P-H $LSD_{0.1} = 0.08$

Table 40

Effect of P Rates on Initial and Postharvest (P-H) NH_4OAc-Extractable Ca of a Tropeptic Eutrustox from Hawaii Waipio Site

Depth (cm)	P Applied, kg/ha							
	0		10		65		140	
	Initial	P-H	Initial	P-H	Initial	P-H	Initial	P-H
	me/100 g							
0-10	6.88	6.58	6.95	6.78	7.36	7.20	7.30	7.14
10-20	6.45	6.30	6.31	6.06	6.58	6.45	6.78	6.66
20-30	6.53	6.46	6.20	6.17	6.38	6.22	6.40	6.31

Initial $LSD_{0.1} = 1.28$

P-H $LSD_{0.1} = 1.00$

Table 41

Effect of P Rates on Initial and Postharvest (P-H) NH_4OAc-Extractable Mg of a Tropeptic Eutrustox from Hawaii Waipio Site

Depth (cm)	P Applied, kg/ha							
	0		10		65		140	
	Initial	P-H	Initial	P-H	Initial	P-H	Initial	P-H
	me/100 g							
0-10	4.34	3.98	4.43	4.14	4.59	4.39	4.66	4.42
10-20	3.86	3.69	3.54	3.33	3.54	3.31	3.74	3.61
20-30	3.59	3.44	3.26	3.09	3.22	3.13	3.38	3.26

Initial $LSD_{0.1} = 0.50$

P-H $LSD_{0.1} = 0.68$

Table 42

Effect of P Rates on Initial and Postharvest (P-H) NH_4OAc-Extractable K of a Tropeptic Eutrustox from Hawaii Waipio Site

Depth (cm)	P Applied, kg/ha							
	0		10		65		140	
	Initial	P-H	Initial	P-H	Initial	P-H	Initial	P-H
	me/100 g							
0-10	2.18	1.64	2.27	1.59	2.24	1.70	2.65	1.92
10-20	1.40	1.23	1.11	1.14	1.40	1.25	1.46	1.56
20-30	0.72	0.83	0.41	0.53	0.48	0.65	0.59	0.73

Initial $LSD_{0.1} = 0.24$

P-H $LSD_{0.1} = 0.38$

Table 43

Effect of P Rates on Initial and Postharvest (P-H) NH_4Cl-Extractable Ca of a Tropeptic Eutrustox from Hawaii Waipio Site

Depth (cm)	P Applied, kg/ha							
	0		10		65		140	
	Initial	P-H	Initial	P-H	Initial	P-H	Initial	P-H
	me/100 g							
0-10	7.19	6.93	7.16	6.98	7.23	7.03	7.28	7.13
10-20	7.10	6.88	6.65	6.53	6.94	6.80	7.11	6.96
20-30	6.24	6.14	6.17	6.08	6.44	6.37	6.41	6.34

Initial $LSD_{0.1} = 1.52$

P-H $LSD_{0.1} = 0.92$

Table 44

Effect of P Rates on Initial and Postharvest (P-H) NH_4Cl-Extractable Mg of a Tropeptic Eutrustox from Hawaii Waipio Site

Depth (cm)	P Applied, kg/ha							
	0		10		65		140	
	Initial	P-H	Initial	P-H	Initial	P-H	Initial	P-H
	me/100 g							
0-10	4.62	4.40	4.84	4.59	4.98	4.73	4.94	4.67
10-20	4.20	3.95	4.21	3.99	4.26	4.01	4.23	3.99
20-30	3.78	3.59	3.69	3.57	3.68	3.55	3.54	3.45

Initial $LSD_{0.1} = 0.52$

P-H $LSD_{0.1} = 0.44$

Table 45

Effect of P Rates on Initial and Postharvest (P-H) NH_4Cl-Extractable K of a Tropeptic Eutrustox from Hawaii Waipio Site

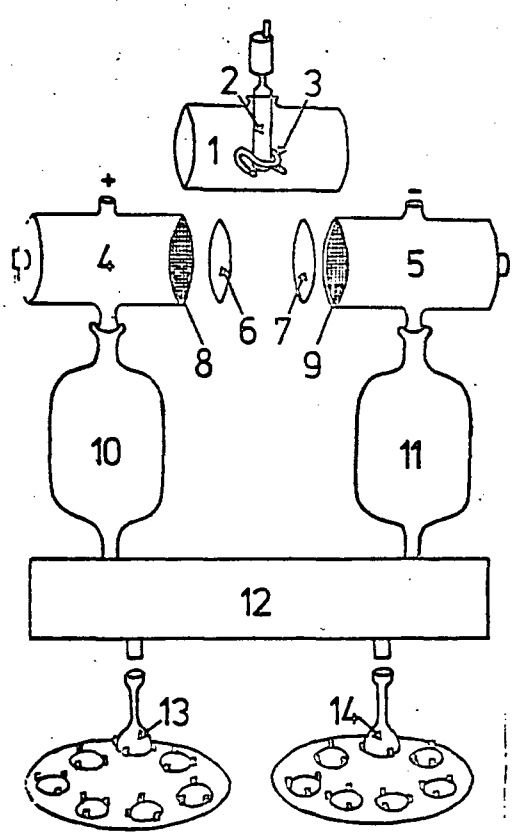
Depth (cm)	P Applied, kg/ha							
	0		10		65		140	
	Initial	P-H	Initial	P-H	Initial	P-H	Initial	P-H
	me/100 g							
0-10	1.35	1.06	1.42	1.10	1.54	1.19	1.54	1.30
10-20	0.95	0.76	0.93	0.95	0.86	0.91	0.92	0.97
20-30	0.59	0.66	0.62	0.65	0.71	0.76	0.68	0.76

Initial $LSD_{0.1} = 0.25$

P-H $LSD_{0.1} = 0.26$

APPENDIX E

SCHEMATIC DIAGRAM OF THE EUF APPARATUS



1 -Central cell for soil suspension
2 -Stirrer
3 -Cooling coil
4,5 -Outside chambers
6 -Anode filter
7 -Cathode filter
8 -Platinum mesh anode
9 -Platinum mesh cathode
10,11 -Holding chambers
12 -Fraction collecting control box
13,14 -Collecting flasks

Fig. 33. Schematic diagram of the EUF apparatus

APPENDIX F

EXTRACTABLE SOIL P AS DETERMINED BY THE MODIFIED TRUOG AND EUF METHODS

Table 46

Extractable Soil P as Determined by the Modified Truog and EUF Methods Hydric Dystrandept

Depth (cm)	P Applied, kg/ha			
	0		750	
	Mod. Truog	EUF	Mod. Truog	EUF
	ppm			
0-10	72.2[c]	0.07[a]	189.3[a]	0.10[a]
10-20	62.1[c]	0.12[a]	109.1[b]	0.10[a]

Averages for a given method followed by the same letter are not significantly different from each other at the 5% level.

Table 47

Extractable Soil P as Determined by the Modified Truog and EUF Methods - Tropeptic Eutrustox Waipio Site

Depth (cm)	P Applied, kg/ha			
	0		140	
	Mod. Truog	EUF	Mod. Truog	EUF
	ppm			
0-10	24.46[b]	0.22[a]	45.26[a]	0.55[a]
10-20	21.18[b]	0.20[a]	27.81[b]	0.18[a]

Averages for a given method followed by the same letter are not significantly different from each other at the 5% level.

APPENDIX G

CORRELATION AND REGRESSION COEFFICIENTS FOR NUTRIENTS EXTRACTED BY DIFFERENT METHODS AND TOTAL NUTRIENT UPTAKE

Table 48

Correlation and Regression Coefficients for Extractable Ca and Na Found by the NH_4OAc, NH_4Cl and EUF Methods and Ca and Na Uptake

(Hydric Dystrandept and Tropeptic Eutrustox)

Extractant/Cations	n	b_0	b_1	r
NH_4O Ac - Ca	8	2.22	3.84	0.918^{**}
NH_4Cl - Ca	8	-7.28	4.97	0.889^{**}
$EUF_I + EUF_{II}$ - Ca	8	34.92	-30.13	-0.824^{*}
EUF_I - Ca	8	31.07	-76.76	-0.703^{ns}
EUF_{II} - Ca	8	36.27	-46.27	-0.862^{**}
EUF_{III} - Ca	8	34.27	-54.57	-0.722^{*}
NH_4OAc - Na	8	-4.32	45.29	0.874^{**}
NH_4Cl - Na	8	-20.28	123.26	0.784^{*}
$EUF_I + EUF_{II}$ - Na	8	0.24	34.24	0.980^{**}
EUF_I - Na	8	-0.56	67.72	0.954^{**}
EUF_{II} - Na	8	1.81	61.09	0.949^{**}
EUF_{III} - Na	8	4.40	108.89	0.569^{ns}

For the equation $y = b_0 + b_1x$, y = Ca or Na uptake (kg/ha); x = extractable M^{n+}; b_0 = intercept; b_1 = slope regression coefficient

^{ns} = not significant

* = significant ($P < 0.05$)

** = highly significant ($P < 0.01$)

Table 49

Correlation and Regression Coefficients for Extractable K and Mg Found by the NH_4OAc, NH_4Cl and EUF Methods and K and Mg Uptake

(Hydric Dystrandept and Tropeptic Eutrustox)

Extractant/Cations	n	b_0	b_1	r
NH_4OAc - K	8	24.36	81.07	0.836^{**}
NH_4Cl - K	8	158.31	-0.06	-0.036^{ns}
$EUF_I + EUF_{II}$ - K	8	43.31	386.11	0.359^{ns}
EUF_I - K	8	234.00	-633.29	-0.258^{ns}
EUF_{II} - K	8	-7.48	954.74	0.662^{ns}
EUF_{III} - K	8	-51.60	1561.27	0.904^{**}
NH_4OAc - Mg	8	-6.98	12.16	0.953^{**}
NH_4Cl - Mg	8	-6.11	11.29	0.965^{**}
$EUF_I + EUF_{II}$ - Mg	8	59.39	-99.82	-0.792^{*}
EUF_I - Mg	8	49.21	-164.61	-0.741^{*}
EUF_{II} - Mg	8	67.09	-207.99	-0.788^{*}
EUF_{III} - Mg	8	36.70	-85.75	-0.201^{ns}

For the equation $y = b_0 + b_1x$, y = K or Mg uptake (kg/ha);
x = extractable M^{n+};
b_0 = intercept;
b_1 = slope regression coefficient

^{ns} = not significant

* = significant ($P < 0.05$)

** = highly significant ($P < 0.01$)

Table 50

Correlation and Regression Coefficients for Extractable P Found by the Modified Truog and EUF Methods and P Uptake

(Hydric Dystrandept and Tropeptic Eutrustox)

Method/P Fraction	n	b_0	b_1	r
Modified Truog	8	47.89	-0.088	-0.281^{ns}
$EUF_I + EUF_{II}$	8	19.26	90.38	0.897^{**}
EUF_I	8	13.78	419.19	0.873^{**}
EUF_{II}	8	21.06	113.53	0.896^{**}
EUF_{III}	8	21.30	105.20	0.746^{*}

For the equation $y = b_0 + b_1x$, y = P uptake (kg/ha);
x = extractable P
b_0 = intercept
b_1 = slope regression coefficient

^{ns} = not significant

* = significant ($P < 0.05$)

** = highly significant ($P < 0.01$)

APPENDIX H

RAW DATA

Table 51

EUF-Extracted Fractions
Hydric Dystrandept - Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0						750					
	Replications						Replications					
	I			II			I			II		
	EUF_I	EUF_{II}	EUF_{III}	EUF_I	EUF_{II}	EUF_{III}	EUF_I	EUF_{II}	EUF_{III}	EUF_I	EUF_{II}	EUF_{III}
	Ca (me/100 g)											
0-10	0.16	0.48	0.33	0.18	0.43	0.27	0.18	0.53	0.39	0.34	0.64	0.50
10-20	0.11	0.31	0.20	0.16	0.40	0.25	0.22	0.60	0.40	0.32	0.66	0.44
	Mg (me/100 g)											
0-10	0.12	0.24	0.05	0.21	0.18	0.06	0.10	0.19	0.04	0.28	0.31	0.18
10-20	0.12	0.26	0.06	0.15	0.27	0.07	0.10	0.21	0.04	0.20	0.27	0.13
	K (me/100 g)											
0-10	0.10	0.10	0.07	0.14	0.14	0.10	0.13	0.14	0.10	0.14	0.14	0.10
10-20	0.13	0.08	0.05	0.12	0.10	0.07	0.10	0.09	0.06	0.10	0.10	0.07
	Na (me/100 g)											
0-10	0.04	0.03	0.01	0.06	0.04	0.02	0.05	0.04	0.01	0.12	0.04	0.07
10-20	0.06	0.03	0.01	0.06	0.03	0.01	0.05	0.03	0.01	0.10	0.05	0.08
	P (ppm)											
0-10	0.03	0.03	0.08	0.03	0.05	0.08	0.03	0.10	0.24	0.03	0.05	0.05
10-20	0.10	0.08	0.18	0.03	0.03	0.06	0.07	0.08	0.22	0.03	0.03	0.03

Table 52

EUF-Extracted Fractions
Tropeptic Eutrustox - Waipio Site

Depth (cm)	P Applied, kg/ha											
	0						750					
	Replications						Replications					
	I			II			I			II		
	EUF_I	EUF_{II}	EUF_{III}	EUF_I	EUF_{II}	EUF_{III}	EUF_I	EUF_{II}	EUF_{III}	EUF_I	EUF_{II}	EUF_{III}
	Ca (me/100 g)											
0-10	0.07	0.16	0.17	0.06	0.16	0.12	0.04	0.11	0.12	0.08	0.23	0.13
10-20	0.07	0.15	0.13	0.06	0.20	0.17	0.04	0.14	0.13	0.10	0.18	0.13
	Mg (me/100 g)											
0-10	0.05	0.13	0.08	0.05	0.12	0.05	0.03	0.07	0.04	0.06	0.16	0.06
10-20	0.04	0.11	0.05	0.04	0.15	0.06	0.02	0.09	0.06	0.02	0.14	0.06
	K (me/100 g)											
0-10	0.11	0.21	0.19	0.12	0.22	0.15	0.06	0.16	0.18	0.17	0.27	0.18
10-20	0.08	0.17	0.14	0.10	0.16	0.11	0.05	0.12	0.13	0.09	0.15	0.12
	Na (me/100 g)											
0-10	0.18	0.16	0.05	0.18	0.12	0.02	0.21	0.25	0.07	0.18	0.12	0.02
10-20	0.19	0.16	0.03	0.10	0.11	0.02	0.20	0.20	0.05	0.17	0.10	0.02
	P (ppm)											
0-10	0.08	0.18	0.07	0.05	0.12	0.12	0.14	0.52	0.42	0.12	0.32	0.42
10-20	0.08	0.15	0.17	0.05	0.13	0.15	0.07	0.07	0.10	0.07	0.17	0.23

Table 53

EUF-Extracted Fractions
Tropeptic Eutrustox - Waialua Site

Depth (cm)	P Applied, kg/ha											
	0						750					
	Replications						Replications					
	I			II			I			II		
	EUF_I	EUF_{II}	EUF_{III}	EUF_I	EUF_{II}	EUF_{III}	EUF_I	EUF_{II}	EUF_{III}	EUF_I	EUF_{II}	EUF_{III}
	Ca (me/100 g)											
0-15	0.13	0.33	0.14	0.17	0.038	0.14	0.18	0.41	0.12	0.17	0.43	0.15
	Mg (me/100 g)											
0-15	0.07	0.24	0.06	0.10	0.22	0.04	0.08	0.16	0.04	0.08	0.20	0.05
	K (me/100 g)											
0-15	0.10	0.12	0.08	0.09	0.11	0.08	0.10	0.11	0.08	0.08	0.10	0.10
	Na (me/100 g)											
0-15	0.10	0.04	0.01	0.05	0.05	0.01	0.09	0.03	0.01	0.10	0.05	0.01
	P (ppm)											
0-15	0.03	0.05	0.14	0.19	0.22	0.41	0.67	1.80	5.07	0.55	1.50	4.95

Table 54

Maize Dry Matter Production (kg/ha)
Hydric Dystrandept - Kukaiau Site

P Applied (kg/ha)	Replications		
	I	II	III
	Grain		
0	2247	4288	3468
40	8285	8446	8239
396	8740	8537	9067
750	8338	8943	9314
	Stover		
0	2118	4943	3607
40	6827	4749	5714
396	4757	6878	7431
750	5438	5940	6119

Table 55

Maize Dry Matter Production (kg/ha)
Tropeptic Eutrustox - Waipio Site

P Applied (kg/ha)	Replications		
	I	II	III
	Grain		
0	5785	6354	7021
10	7799	6547	8364
65	8103	8690	9228
140	9462	7074	9077
	Stalks		
0	7818	7347	7474
10	7147	4496	6506
65	4813	7587	6542
140	8855	4022	7451
	Leaves		
0	3648	2899	3615
10	3107	2245	2286
65	3179	3009	2857
140	3160	2888	2798

Table 56

Effect of P Rates on Modified and Truog-extractable Soil P of a Hydric Dystrandept from Hawaii
Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0			40			396			750		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	ppm											
0-10	78.91	68.30	69.38	118.94	101.44	126.84	171.36	163.65	184.49	190.05	189.30	188.55
10-20	62.14	58.47	65.82	78.76	69.91	81.62	99.88	91.91	92.90	122.00	109.08	96.15
20-30	63.04	66.05	66.03	75.86	69.70	73.47	77.76	72.41	75.08	69.26	67.47	71.06
30-45	79.52	90.25	68.79	68.81	60.26	77.36	76.48	67.46	71.97	77.43	81.23	80.63
45-60	82.75	73.49	64.23	77.45	79.50	71.55	76.96	68.57	72.76	79.13	74.11	76.62

Table 57

Effect of P Rates on Modified Truog-extractable Soil P of a Tropeptic Eutrustox from Hawaii
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	ppm											
0-10	25.46	22.35	25.56	28.43	26.70	30.79	36.65	39.39	38.02	48.88	45.26	41.63
10-20	21.18	19.78	22.57	23.60	25.78	21.70	30.97	28.06	23.12	30.41	28.20	24.81
20-30	15.27	13.09	17.45	20.81	20.75	18.36	19.45	15.64	18.94	15.47	12.26	15.36
30-45	11.36	12.43	10.34	12.38	11.66	12.02	11.34	12.42	11.88	9.86	9.63	9.40
45-60	3.08	3.87	2.30	5.05	6.25	3.85	6.15	6.95	5.35	4.65	5.44	3.86

Table 58

Effect of P Rates on Modified Truog-extractable Soil P of a Tropeptic Eutrustox from Hawaii
Waialua Site

Depth (cm	P Applied, kg/ha											
	0				98				196			
	Replications (Field)											
	I	II	III	IV	I	II	III	IV	I	II	III	IV
	ppm											
0-15	18.82	19.29	15.03	17.71	112.01	94.78	91.75	103.51	216.96	224.34	204.46	215.25
15-30	16.27	15.54	18.52	14.20	21.95	22.43	24.24	22.87	17.81	19.55	21.36	20.91
30-45	9.04	6.29	7.08	7.47	10.48	9.13	7.06	8.88	9.02	9.11	9.42	7.02
45-60	7.26	5.42	5.89	6.19	9.54	6.19	7.04	7.59	5.69	6.81	5.46	5.99

Table 59

Effect of P Rates on NH_4OAc-CEC of a
Hydric Dystrandept from Hawaii
Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0			40			396			750		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	37.20	35.68	34.17	36.16	38.17	34.15	38.38	39.33	37.43	39.81	40.99	38.63
10-20	43.42	41.75	39.10	42.97	43.78	44.60	40.71	41.68	39.71	44.26	42.89	42.63
20-30	49.94	49.31	50.56	52.05	50.89	48.75	44.62	44.44	44.25	50.94	49.12	47.29
30-45	50.79	50.05	50.31	46.46	49.04	51.63	48.56	48.90	49.29	46.56	46.12	47.00
45-60	48.91	47.24	46.08	47.99	46.71	47.35	41.58	46.76	37.06	49.78	48.84	50.71

Table 60

Effect of P Rates on NH_4Cl-CEC of a
Hydric Dystrandept from Hawaii
Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0			40			396			750		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	15.60	16.36	17.84	17.37	16.90	16.42	18.07	17.57	18.46	18.31	18.87	19.42
10-20	20.41	22.57	21.74	25.41	22.98	21.85	22.63	21.64	20.65	21.41	22.61	23.22
20-30	27.86	29.11	26.61	30.49	32.60	31.54	25.39	24.28	26.50	26.41	23.27	29.54
30-45	33.47	34.31	35.64	29.17	28.71	28.25	34.23	33.96	33.72	27.39	29.12	28.66
45-60	33.07	33.51	33.94	32.28	33.82	33.36	29.56	32.25	28.68	29.15	31.75	31.30

Table 61

Effect of P Rates on NH_4OAc-CEC of a
Tropeptic Eutrustox from Hawaii
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	16.70	17.28	17.86	18.01	17.08	16.63	17.46	15.62	16.78	17.16	18.14	19.12
10-20	15.92	14.11	14.58	13.72	14.96	16.19	13.57	16.00	15.44	17.68	18.52	19.98
20-30	12.97	16.06	14.52	13.48	16.27	14.88	15.15	14.53	14.84	12.13	15.83	13.98
30-45	15.32	14.26	14.79	14.52	16.98	15.25	14.24	15.12	13.36	13.02	16.17	14.60
45-60	10.70	15.08	12.89	12.47	11.82	11.90	13.87	12.70	13.54	13.53	12.73	12.11

Table 62

Effect of P Rates on NH_4Cl-CEC of a
Tropeptic Eutrustox from Hawaii
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	13.67	14.10	13.96	15.45	14.12	12.98	15.27	14.38	13.12	14.76	13.58	15.32
10-20	12.55	13.94	11.73	13.67	13.34	12.00	13.00	12.22	11.43	12.88	13.35	13.82
20-30	13.46	13.03	12.61	13.74	12.74	11.74	12.81	12.80	12.81	12.02	12.00	12.02
30-45	11.40	12.98	10.40	9.72	11.31	12.90	11.91	11.90	11.91	10.31	11.04	11.04
45-60	10.63	10.88	11.12	11.82	12.33	9.82	11.38	12.30	12.38	9.46	11.40	10.46

Table 63

Effect of P Rates on NH_4OAc-CEC of a
Tropeptic Eutrustox from Hawaii
Waialua Site

Depth (cm)	P Applied, kg/ha											
	0				98				196			
	Replications (Field)											
	I	II	III	IV	I	II	III	IV	I	II	III	IV
	me/100g											
0-15	18.97	19.70	19.07	18.29	18.74	19.92	19.95	18.36	20.25	20.00	18.89	19.91
15-30	16.81	16.70	15.62	17.74	17.75	17.00	18.40	17.58	17.64	18.64	16.00	16.73
30-45	13.42	15.19	13.55	15.78	15.46	14.63	13.24	15.00	15.66	13.80	14.71	15.71
45-60	13.67	12.28	18.76	14.22	13.31	12.46	13.82	13.86	13.62	14.00	14.30	13.04

Table 64

Effect of P Rates on Initial NH_4OAc-extractable Ca
of a Hydric Dystrandept from Hawaii
Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0			40			396			750		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	1.79	1.42	1.86	1.69	1.83	1.64	2.50	2.29	2.23	3.75	2.61	3.18
10-20	1.34	1.48	1.74	1.98	1.85	1.92	2.39	2.17	2.13	2.58	2.29	2.16
20-30	1.73	1.93	1.86	2.09	2.36	2.22	3.09	3.16	3.12	3.27	3.32	3.38
30-45	1.18	1.52	1.35	2.19	2.24	2.14	3.23	3.28	3.00	3.48	3.79	3.18
45-60	2.58	2.57	2.56	2.54	2.10	2.14	3.03	2.88	2.96	3.23	3.16	3.08

Table 65

Effect of P Rates on Initial NH_4OAc-extractable Mg
of a Hydric Dystrandept from Hawaii
Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0			40			396			750		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	1.71	1.70	1.40	1.84	1.79	1.74	1.87	1.76	1.65	1.80	1.65	1.94
10-20	2.07	2.06	2.07	2.08	1.92	2.00	1.57	1.64	1.69	1.75	1.61	1.71
20-30	2.92	3.17	3.12	2.67	2.56	2.62	2.58	2.36	2.47	2.23	2.62	2.42
30-45	2.26	2.47	2.23	2.45	2.52	2.38	2.50	2.16	2.15	2.33	2.38	2.28
45-60	1.73	1.90	1.98	2.08	2.14	2.02	1.80	1.91	1.62	1.80	1.89	1.72

Table 66

Effect of P Rates on Initial NH_4OAc-extractable K
of a Hydric Dystrandept from Hawaii
Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0			40			396			750		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	0.87	0.81	0.88	0.78	0.84	0.91	0.86	0.78	0.86	0.97	0.89	0.86
10-20	0.80	0.75	0.78	0.62	0.74	0.79	0.66	0.60	0.67	0.59	0.60	0.66
20-30	0.68	0.74	0.76	0.46	0.60	0.73	0.48	0.46	0.51	0.46	0.51	0.42
30-45	0.65	0.63	0.61	0.47	0.52	0.57	0.35	0.42	0.37	0.42	0.44	0.45
45-60	0.70	0.71	0.65	0.58	0.56	0.55	0.57	0.65	0.49	0.53	0.63	0.42

Table 67

Effect of P Rates on Initial NH_4OAc-extractable Na
of a Hydric Dystrandept from Hawaii
Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0			40			396			750		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	0.16	0.18	0.15	0.16	0.19	0.14	0.19	0.20	0.18	0.22	0.20	0.19
10-20	0.27	0.32	0.30	0.21	0.22	0.24	0.21	0.24	0.22	0.20	0.20	0.21
20-30	0.35	0.36	0.32	0.28	0.31	0.34	0.33	0.34	0.34	0.34	0.35	0.33
30-45	0.34	0.23	0.28	0.25	0.22	0.24	0.28	0.23	0.26	0.27	0.28	0.27
45-60	0.37	0.35	0.41	0.36	0.39	0.32	0.38	0.35	0.36	0.34	0.37	0.32

Table 68

Effect of P Rates on Initial NH_4Cl-extractable Ca of a Hydric Dystrandept from Hawaii
Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0			40			396			750		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	2.67	2.99	2.95	3.44	3.54	3.70	4.44	4.61	4.26	4.99	4.58	4.77
10-20	2.47	2.86	2.66	3.33	3.23	3.58	4.16	3.90	4.03	4.33	4.09	4.40
20-30	2.98	3.10	2.86	4.96	4.97	4.98	4.30	4.53	4.80	4.56	4.33	4.55
30-45	3.14	3.15	3.16	3.60	4.01	3.81	4.67	4.58	4.76	4.15	4.26	4.34
45-60	2.92	3.06	3.19	3.24	3.42	3.67	3.86	3.45	3.66	3.77	3.60	3.68

Table 69

Effect of P Rates on Initial NH_4Cl-extractable Mg
of a Hydric Dystrandept from Hawaii
Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0			40			396			750		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	1.73	1.51	1.84	1.59	1.66	1.74	1.76	1.86	1.66	1.85	1.70	1.86
10-20	2.11	1.91	2.01	1.63	1.75	1.87	1.45	1.66	1.84	1.50	1.73	1.76
20-30	2.37	2.57	2.66	2.18	2.28	2.38	1.90	1.87	1.86	2.15	2.14	1.91
30-45	2.21	2.42	2.00	2.70	2.54	2.37	1.76	1.78	1.80	1.90	2.12	2.04
45-60	1.24	1.31	1.18	2.01	1.92	1.96	1.73	1.52	1.68	1.87	1.92	1.82

Table 70

Effect of P Rates on Initial NH_4Cl-extractable K
of a Hydric Dystrandept from Hawaii
Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0			40			396			750		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	0.76	0.80	0.72	0.68	0.72	0.78	0.60	0.65	0.69	0.83	0.76	0.86
10-20	0.73	0.76	0.68	0.65	0.67	0.66	0.54	0.48	0.59	0.62	0.61	0.64
20-30	0.54	0.65	0.60	0.30	0.40	0.38	0.33	0.34	0.34	0.40	0.46	0.49
30-45	0.50	0.54	0.49	0.46	0.43	0.40	0.45	0.45	0.40	0.29	0.36	0.33
45-60	0.52	0.66	0.74	0.56	0.51	0.46	0.58	0.55	0.56	0.50	0.59	0.56

Table 71

Effect of P Rates on Initial NH_4Cl-extractable Na
of a Hydric Dystrandept from Hawaii
Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0			40			396			750		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	0.20	0.19	0.17	0.18	0.20	0.17	0.20	0.22	0.20	0.20	0.23	0.25
10-20	0.23	0.27	0.25	0.20	0.28	0.22.	0.21	0.26	0.24	0.23	0.26	0.24
20-30	0.56	0.60	0.52	0.48	0.51	0.50	0.40	0.39	0.39	0.30	0.32	0.39
30-45	0.36	0.53	0.44	0.42	0.42	0.45	0.36	0.38	0.37	0.26	0.28	0.26
45-60	0.51	0.54	0.52	0.49	0.50	0.54	0.50	0.55	0.59	0.48	0.41	0.56

Table 72

Effect of P Rates on Initial NH_4OAc-extractable Ca
of a Tropeptic Eutrustox from Hawaii
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	7.11	6.88	6.65	6.62	6.82	7.41	7.30	7.52	7.25	7.13	7.24	7.52
10-20	6.63	6.16	6.57	6.55	5.50	6.88	6.58	6.30	6.86	6.42	7.00	6.92
20-30	6.38	6.58	6.63	6.75	5.28	6.56	5.99	6.10	7.04	6.40	6.18	6.62
30-45	6.37	6.03	4.71	6.65	5.28	5.13	6.36	6.05	5.76	5.82	5.50	4.73
45-60	6.53	5.69	4.79	5.82	4.93	4.79	5.69	5.66	5.62	5.90	5.65	4.91

Table 73

Effect of P Rates on Initial NH_4OAc-extractable Mg
of a Tropeptic Eutrustox from Hawaii
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	4.29	4.34	4.38	4.57	4.10	4.62	4.52	4.37	4.87	4.84	4.66	4.47
10-20	3.97	3.75	3.86	3.42	3.40	3.80	3.74	3.33	3.54	3.80	3.69	3.74
20-30	3.86	3.46	3.47	3.25	3.27	3.26	3.16	3.13	3.37	3.43	3.38	3.33
30-45	3.35	3.28	3.21	3.18	3.00	3.07	2.93	3.00	3.15	3.29	3.02	3.00
45-60	3.00	3.13	3.24	3.00	2.90	2.97	2.88	2.90	3.00	3.02	2.92	2.80

Table 74

Effect of P Rates on Initial NH_4OAc-extractable K
of a Tropeptic Eutrustox from Hawaii
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	2.31	2.00	2.24	2.07	2.13	2.22	2.18	2.15	2.38	2.56	2.50	2.90
10-20	1.30	1.39	1.52	1.04	1.11	1.18	1.32	1.50	1.39	1.37	1.55	1.46
20-30	0.77	0.72	0.66	0.50	0.34	0.38	0.53	0.48	0.42	0.59	0.74	0.44
30-45	0.26	0.29	0.25	0.23	0.24	0.23	0.26	0.27	0.22	0.28	0.22	0.29
45-60	0.17	0.13	0.15	0.16	0.14	0.13	0.16	0.14	0.11	0.12	0.14	0.16

Table 75

Effect of P Rates on Initial NH_4OAc-extractable Na
of a Tropeptic Eutrustox from Hawaii
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	0.32	0.28	0.35	0.38	0.35	0.30	0.37	0.39	0.34	0.38	0.40	0.35
10-20	0.29	0.25	0.22	0.28	0.25	0.24	0.20	0.23	0.25	0.26	0.20	0.24
20-30	0.16	0.18	0.17	0.20	0.21	0.20	0.17	0.15	0.16	0.18	0.17	0.16
30-45	0.26	0.28	0.24	0.22	0.24	0.23	0.27	0.26	0.25	0.25	0.27	0.28
45-60	0.19	0.17	0.16	0.16	0.18	0.15	0.17	0.16	0.13	0.14	0.13	0.12

Table 76

Effect of P Rates on Initial NH_4Cl-extractable Ca of a Tropeptic Eutrustox from Hawaii
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	7.02	7.36	7.19	6.92	7.26	7.29	7.56	6.90	7.23	7.11	7.45	7.28
10-20	6.92	7.23	7.16	6.11	7.02	6.84	7.28	6.39	7.14	6.99	7.22	7.13
20-30	6.42	6.24	6.06	6.07	5.72	6.71	6.99	6.16	6.17	6.77	6.97	5.50
30-45	6.27	6.23	5.44	5.82	5.33	6.58	5.94	6.04	5.91	5.20	6.25	5.40
45-60	6.00	6.17	5.34	5.24	5.18	5.62	5.24	5.64	5.59	5.20	6.25	5.40

Table 77

Effect of P Rates on Initial NH_4Cl-extractable Mg
of a Tropeptic Eutrustox from Hawaii
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	4.42	4.64	4.80	4.84	5.02	4.67	5.20	4.98	4.75	5.27	4.75	4.79
10-20	4.00	4.35	4.20	4.16	4.26	4.21	4.23	4.30	4.26	4.10	4.36	4.23
20-30	3.70	3.85	3.78	3.42	3.69	3.96	3.48	3.87	3.68	3.57	3.54	3.51
30-45	3.48	3.42	3.36	3.18	3.52	3.44	3.27	3.60	3.43	3.42	3.32	3.23
45-60	3.28	3.23	3.18	3.21	3.12	3.33	3.10	3.40	3.20	3.25	3.08	3.19

Table 78

Effect of P Rates on Initial NH_4Cl-extractable K
of a Tropeptic Eutrustox from Hawaii
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	1.20	1.23	1.62	1.20	1.62	1.45	1.43	1.66	1.54	1.48	1.71	1.53
10-20	0.81	1.00	1.04	0.92	0.97	0.90	0.90	0.82	0.87	0.98	0.92	0.87
20-30	0.57	0.50	0.70	0.64	0.66	0.56	0.71	0.78	0.64	0.72	0.68	0.64
30-45	0.40	0.43	0.44	0.54	0.38	0.46	0.46	0.56	0.51	0.49	0.44	0.46
45-60	0.30	0.20	0.32	0.24	0.34	0.30	0.26	0.46	0.24	0.34	0.25	0.23

Table 79

Effect of P Rates on Initial NH_4Cl-extractable Na
of a Tropeptic Eutrustox from Hawaii
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	0.22	0.24	0.25	0.25	0.27	0.24	0.28	0.26	0.24	0.29	0.25	0.30
10-20	0.17	0.18	0.14	0.14	0.18	0.14	0.17	0.18	0.14	0.16	0.15	0.14
20-30	0.12	0.15	0.13	0.13	0.14	0.12	0.14	0.15	0.12	0.14	0.13	0.13
30-45	0.28	0.27	0.30	0.29	0.32	0.30	0.24	0.30	0.27	0.30	0.24	0.25
45-60	0.15	0.13	0.17	0.16	0.15	0.12	0.15	0.18	0.16	0.16	0.18	0.12

Table 80

Effect of P Rates on NH_4OAc-extractable Ca
of a Tropeptic Eutrustox from Hawaii
Waialua Site

Depth (cm)	P Applied, kg/ha											
	0				98				196			
	Replications (Field)											
	I	II	III	IV	I	II	III	IV	I	II	III	IV
	me/100g											
0-15	1.30	1.38	1.28	1.16	1.25	1.15	1.51	1.37	1.00	1.30	1.31	1.64
15-30	1.72	1.68	1.82	1.66	1.73	1.65	1.98	2.05	1.90	2.06	1.89	1.79
30-45	3.59	3.87	3.50	3.50	3.17	3.17	3.10	3.24	3.51	3.61	3.77	3.56
45-60	5.00	5.67	5.16	5.85	5.23	5.64	5.70	5.50	5.25	5.76	5.46	5.75

Table 81

Effect of P fertilization on NH_4OAc-extractable Mg
of a Tropeptic Eutrustox from Hawaii
Waialua Site

Depth (cm)	P Applied, kg/ha											
	0				98				196			
	Replications (Field)											
	I	II	III	IV	I	II	III	IV	I	II	III	IV
	me/100g											
0-15	0.30	0.27	0.29	0.33	0.30	0.37	0.45	0.42	0.24	0.31	0.35	0.51
15-30	0.31	0.34	0.20	0.24	0.48	0.39	0.33	0.35	0.36	0.54	0.28	0.32
30-45	0.46	0.87	0.49	0.52	0.65	0.47	0.51	0.79	0.61	0.53	0.67	0.49
45-60	0.68	0.86	0.72	0.84	1.02	0.75	0.79	1.04	0.82	0.79	0.55	0.80

Table 82

Effect of P Rates on NH_4OAc-extractable K
of a Tropeptic Eutrustox from Hawaii
Waialua Site

Depth (cm)	P Applied, kg/ha											
	0				98				196			
	Replications (Field)											
	I	II	III	IV	I	II	III	IV	I	II	III	IV
	me/100g											
0-15	0.90	1.23	0.94	1.18	1.28	1.05	0.84	1.20	0.90	0.98	0.94	1.31
15-30	0.30	0.28	0.38	0.41	0.31	0.24	0.32	0.38	0.24	0.30	0.35	0.53
30-45	0.29	0.21	0.30	0.24	0.19	0.31	0.22	0.30	0.20	0.26	0.29	0.22
45-60	0.22	0.32	0.26	0.24	0.21	0.32	0.20	0.28	0.25	0.24	0.21	0.37

Table 83

Effect of P Rates on NH_4OAc-extractable Na
of a Tropeptic Eutrustox from Hawaii
Waialua Site

Depth (cm)	P Applied, kg/ha											
	0				98				196			
	Replications (Field)											
	I	II	III	IV	I	II	III	IV	I	II	III	IV
	me/100g											
0-15	0.11	0.17	0.18	0.15	0.14	0.10	0.16	0.12	0.13	0.17	0.12	0.16
15-30	0.21	0.20	0.18	0.20	0.17	0.16	0.10	0.18	0.24	0.20	0.20	0.25
30-45	0.25	0.22	0.19	0.31	0.25	0.19	0.23	0.29	0.23	0.23	0.28	0.31
45-60	0.21	0.27	0.22	0.29	0.30	0.20	0.20	0.31	0.13	0.23	0.32	0.29

Table 84

Effect of P Rates on Postharvest NH_4OAc-extractable Ca
of a Hydric Dystrandept from Hawaii
Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0			40			396			750		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	1.44	1.28	1.61	1.50	1.70	1.30	1.94	1.86	1.86	3.00	2.70	2.25
10-20	1.29	1.35	1.40	1.90	1.49	1.63	2.35	2.27	2.43	2.76	2.60	2.78
20-30	1.56	1.66	1.76	2.00	2.21	2.00	3.00	3.00	2.90	3.19	3.25	3.12

Table 85

Effect of P Rates on Postharvest NH_4OAc- extractable Mg
of a Hydric Dystrandept from Hawaii
Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	1.52	1.49	1.46	1.40	1.36	1.44	1.38	1.37	1.40	1.51	1.52	1.61
10-20	2.24	2.22	2.19	1.80	1.99	2.00	1.50	1.49	1.49	1.73	1.75	1.77
20-30	2.68	2.54	2.81	2.70	2.62	2.65	2.60	2.56	2.67	2.44	2.43	2.52

Table 86

Effect of P Rates on Postharvest NH_4OAc-extractable K
of a Hydric Dystrandept from Hawaii
Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	0.62	0.64	0.60	0.63	0.67	0.66	0.74	0.68	0.75	0.87	0.78	0.78
10-20	0.62	0.66	0.66	0.56	0.66	0.63	0.60	0.56	0.56	0.52	0.56	0.51
20-30	0.62	0.68	0.57	0.43	0.60	0.58	0.46	0.42	0.41	0.42	0.46	0.43

Table 87

Effect of P Rates on Postharvest NH_4Cl-extractable Ca of a Hydric Dystrandept from Hawaii
Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	2.50	2.70	2.55	3.25	3.48	3.58	4.16	4.14	4.10	4.69	4.50	4.45
10-20	2.27	2.47	2.39	3.24	3.22	3.20	4.20	4.30	4.30	4.42	4.22	4.50
20-30	2.47	2.85	2.42	4.36	4.58	4.79	4.20	4.32	4.40	4.40	4.20	4.30

Table 88

Effect of P Rates on Postharvest NH_4Cl-extractable Mg
of a Hydric Dystrandept from Hawaii
Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	1.25	1.28	1.21	1.16	1.14	1.11	1.15	1.44	1.23	1.45	1.50	1.52
10-20	1.98	2.05	2.02	1.43	1.60	1.77	1.60	1.68	1.56	1.88	1.48	1.68
20-30	2.45	2.46	2.46	2.43	2.48	2.52	2.25	2.26	2.28	2.14	2.14	2.28

Table 89

Effect of P Rates on Postharvest NH_4Cl-extractable K of a Hydric Dystrandept from Hawaii
Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	0.56	0.60	0.65	0.50	0.60	0.56	0.50	0.52	0.51	0.70	0.69	0.70
10-20	0.52	0.56	0.60	0.54	0.55	0.60	0.40	0.43	0.47	0.50	0.50	0.54
20-30	0.51	0.54	0.57	0.32	0.33	0.35	0.30	0.32	0.30	0.40	0.40	0.43

Table 90

Effect of P Rates on Postharvest NH_4OAc-extractable Ca
of a Tropeptic Eutrustox from Hawaii
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	6.55	6.74	6.45	6.86	6.65	6.81	7.10	7.36	7.13	7.04	7.00	7.39
10-20	6.38	6.24	6.28	6.40	5.38	6.41	6.32	6.25	6.78	6.42	6.85	6.72
20-30	6.43	6.51	6.42	6.22	6.16	6.13	6.22	6.15	6.50	6.30	6.16	6.47

Table 91

Effect of P Rates on Postharvest NH_4OAc-extractable Mg
of a Tropeptic Eutrustox from Hawaii
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	4.03	4.01	3.89	4.00	4.20	4.21	4.32	4.18	4.67	4.63	4.40	4.22
10-20	3.71	3.71	3.64	3.20	3.20	3.58	3.54	3.13	3.27	3.71	3.49	3.61
20-30	3.64	3.30	3.37	3.10	3.10	3.06	3.14	3.03	3.22	3.23	3.33	3.21

Table 92

Effect of P Rates on Postharvest NH_4OAc-extractable K
of a Tropeptic Eutrustox from Hawaii
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	1.69	1.68	1.57	1.75	1.43	1.59	1.58	1.70	1.82	2.02	1.82	1.92
10-20	1.23	1.20	1.25	1.25	1.14	1.04	1.20	1.28	1.27	1.56	1.64	1.48
20-30	0.89	0.84	0.76	0.66	0.46	0.48	0.73	0.61	0.60	0.67	0.79	0.74

Table 93

Effect of P Rates on Postharvest NH_4Cl-extractable Ca
of a Tropeptic Eutrustox from Hawaii
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	6.90	6.97	6.91	6.98	7.00	6.97	7.20	6.80	7.10	7.00	7.30	7.00
10-20	6.83	6.80	6.90	5.97	6.97	6.70	7.10	6.30	7.00	6.97	7.00	6.90
20-30	6.34	6.08	6.00	5.90	6.05	6.30	6.90	6.12	6.10	6.38	6.42	6.23

Table 94

Effect of P Rates on Postharvest NH_4Cl-extractable Mg
of a Tropeptic Eutrustox from Hawaii
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	4.36	4.43	4.40	4.58	4.70	4.50	4.80	4.80	4.60	4.90	4.50	4.60
10-20	3.92	4.00	3.94	3.98	4.00	4.00	3.97	4.18	3.98	3.90	4.07	3.99
20-30	3.55	3.61	3.60	3.42	3.48	3.80	3.52	3.58	3.56	3.44	3.40	3.50

Table 95

Effect of P Rates on Postharvest NH_4Cl-extractable K
of a Tropeptic Eutrustox from Hawaii
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	me/100g											
0-10	1.00	1.09	1.09	1.15	1.00	1.16	1.22	1.14	1.20	1.22	1.38	1.30
10-20	0.73	0.70	0.84	0.95	0.98	0.93	0.94	0.90	0.90	0.97	0.96	0.98
20-30	0.63	0.61	0.74	0.68	0.66	0.60	0.78	0.78	0.70	0.78	0.75	0.76

Table 96

Effect of P fertilization on the levels
of nutrients in maize grain
Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0			40			396			750		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	percent											
N	1.29	1.20	1.04	1.38	1.43	1.58	1.44	1.32	1.42	1.48	1.40	1.48
P	0.28	0.27	0.24	0.33	0.35	0.37	0.38	0.31	0.29	0.34	0.34	0.43
K	0.21	0.23	0.20	0.28	0.36	0.31	0.31	0.22	0.19	0.28	0.32	0.35
Ca	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Mg	0.11	0.09	0.08	0.13	0.14	0.16	0.15	0.12	0.11	0.14	0.13	0.19
Na	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.03
S	0.08	0.07	0.06	0.08	0.08	0.09	0.09	0.08	0.08	0.09	0.08	0.09

Table 97

Effect of P fertilization on the levels of nutrients in maize stover
Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0			40			396			750		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	percent											
N	0.43	0.26	0.26	0.32	0.28	0.36	0.31	0.30	0.24	0.31	0.28	0.34
P	0.10	0.08	0.08	0.08	0.08	0.08	0.09	0.08	0.08	0.08	0.08	0.08
K	0.88	1.08	1.33	1.26	1.98	1.31	1.73	1.28	1.91	1.67	1.77	1.27
Ca	0.20	0.14	0.12	0.15	0.12	0.14	0.12	0.12	0.14	0.15	0.13	0.15
Mg	0.23	0.12	0.11	0.12	0.09	0.11	0.10	0.11	0.10	0.11	0.09	0.11
Na	0.05	0.03	0.03	0.04	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.03
S	0.04	0.02	0.02	0.03	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02

Table 98

Effect of P fertilization on the levels of nutrients in maize cobs

Kukaiau Site

Depth (cm)	P Applied, kg/ha											
	0			40			396			750		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	percent											
N	0.36	0.52	0.32	0.55	0.43	0.58	0.50	0.60	0.36	0.58	0.46	0.46
P	0.09	0.11	0.08	0.09	0.09	0.10	0.10	0.09	0.08	0.10	0.08	0.09
K	0.57	0.64	0.67	0.59	0.56	0.64	0.51	0.58	0.49	0.47	0.50	0.49
Ca	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Mg	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Na	0.04	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.02	0.03	0.03
S	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01

Table 99

Effect of P fertilization on the levels of nutrients in maize grain
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	percent											
N	1.46	1.51	1.61	1.68	1.54	1.76	1.64	1.70	1.91	1.92	1.72	1.36
P	0.55	0.51	0.43	0.60	0.55	0.53	0.74	0.73	0.81	0.61	0.70	0.56
K	0.40	0.38	0.34	0.42	0.41	0.33	0.44	0.53	0.54	0.40	0.49	0.37
Ca	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Mg	0.19	0.18	0.17	0.22	0.20	0.21	0.26	0.23	0.28	0.21	0.24	0.21
Na	0.03	0.03	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.03	0.03
S	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09

Table 100

Effect of P fertilization on the levels of nutrients in maize stalks
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	percent											
N	0.34	0.32	0.38	0.36	0.40	0.37	0.04	0.42	0.50	0.52	0.43	0.54
P	0.10	0.09	0.09	0.08	0.08	0.09	0.08	0.09	0.09	0.11	0.09	0.10
K	2.83	2.31	2.94	2.30	2.52	2.56	2.27	2.71	3.09	2.13	3.19	2.69
Ca	0.15	0.14	0.15	0.16	0.16	0.16	0.15	0.14	0.15	0.17	0.14	0.17
Mg	0.28	0.20	0.22	0.26	0.27	0.25	0.24	0.22	0.26	0.22	0.23	0.25
Na	0.09	0.08	0.10	0.10	0.11	0.10	0.10	0.09	0.10	0.08	0.09	0.08
S	0.06	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.05	0.06	0.07

Table 101

Effect of P fertilization on the levels of nutrients in maize leaves
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	percent											
N	0.78	0.94	0.86	1.04	1.04	0.90	1.06	1.20	0.92	1.04	0.98	1.04
P	0.16	0.17	0.14	0.12	0.13	0.14	0.12	0.17	0.14	0.15	0.13	0.16
K	0.29	0.47	0.43	0.60	0.48	0.37	0.38	0.56	0.45	0.42	0.47	0.62
Ca	0.42	0.51	0.41	0.50	0.40	0.36	0.45	0.46	0.40	0.43	0.37	0.51
Mg	0.50	0.59	0.48	0.57	0.50	0.46	0.44	0.51	0.49	0.46	0.48	0.59
Na	0.09	0.11	0.12	0.15	0.13	0.10	0.09	0.14	0.12	0.10	0.10	0.16
S	0.07	0.11	0.08	0.11	0.09	0.08	0.09	0.12	0.08	0.09	0.08	0.10

Table 102

Effect of P fertilization on the levels of nutrients in maize cobs
Waipio Site

Depth (cm)	P Applied, kg/ha											
	0			10			65			140		
	Replications (Field)											
	I	II	III	I	II	III	I	II	III	I	II	III
	percent											
N	0.40	0.35	0.46	0.35	0.35	0.40	0.31	0.37	0.29	0.57	0.42	0.31
P	0.09	0.08	0.10	0.08	0.08	0.09	0.08	0.09	0.08	0.13	0.09	0.09
K	0.43	0.35	0.45	0.42	0.30	0.35	0.42	0.34	0.33	0.43	0.44	0.30
Ca	0.07	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.07	0.08
Mg	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.06	0.01	0.02
Na	0.03	0.03	0.04	0.04	0.05	0.04	0.04	0.04	0.03	0.04	0.04	0.04
S	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

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